Alternative Workflow for 3D Basin Modeling in Areas of Structural Complexity - Case Study from the Middle Magdalena Valley, Colombia*

Román González[1], Carlos Suarez[1], and Luis Rojas[1]

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[1]ECOPETROL, S.A., Bogotá, Colombia (roman.gonzalez@ecopetrol.com.co)

Abstract

In recent years there have been many developments concerning basin modeling in structurally complex areas. However the full application of these improvements in 3D modeling is not widespread because it requires the use of 3D structural restoration (or restoration on many cross sections), which is a time-demanding process that is not always available at the basin scale. Although a standard basin model could give a faster overview of the petroleum system elements in this kind of basin, it is an option that has to be carefully considered in structured settings because it may lead to pitfalls that could create a misunderstanding of the basin potential. Although there is not an available regional 3D structural restoration in the Middle Magdalena Valley Basin (MMVB) of Colombia, we present the main challenges and key alternative procedures that were used to get a reliable model in an area of 11.000 km^2 in the central portion of the basin with a grid spacing of 100m. This model integrates previous basin models, revised seismic interpretation, regional stratigraphy and calibration data from wells. The MMVB is located between the Central and Eastern Cordillera of Colombia, in the NW portion of the Andean range, which account for more than 2 billion barrels of production over the last century. Most oil production from this basin comes from structural plays on Tertiary fluvial reservoirs that range in age between Paleocene to Miocene. While it is evident that it is a mature basin in terms of production on Tertiary structural traps, there is still uncertainty in the geological and thermal evolution that become constraints to understand other play concepts.

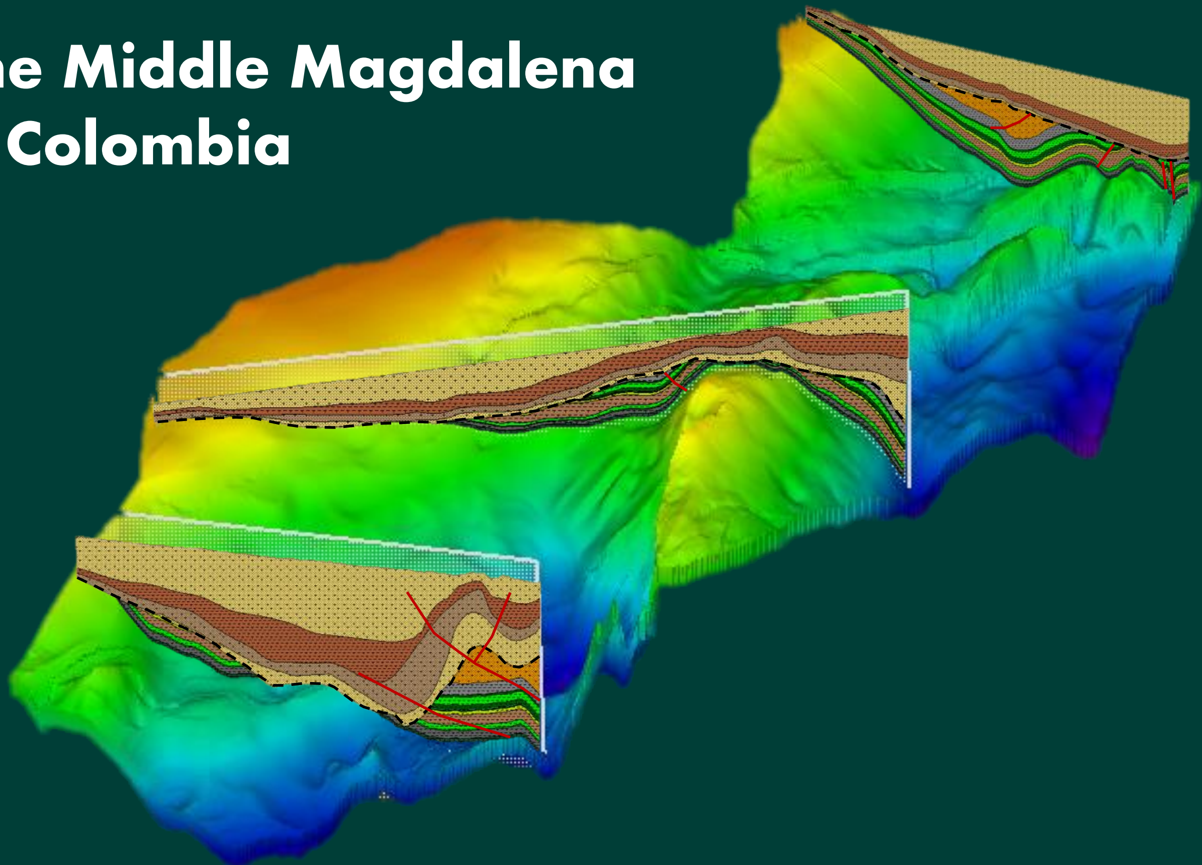
The MMVB is an intramontane basin that has undergone a complex evolution from a divergent to convergent regime, where the present day geometry is characterized by dipping and repeated faulted beds that represent an inherent problem for paleo-geometric reconstruction by mean of the back-stripping method used in conventional modeling. Addition of paleothickness and particularly, correction of original thickness is a procedure commonly used for solving this issue, however taking into account that modeling software use linear interpolation throughout time, a wrong time selection for the thickness correction could deal to minor corrections or even worst results. In our model, we have focused the thickness corrections on the most sensible control points that could produce more realistic results, which are those related to the main deformation events. A comparison between maturity maps derived from models without correction, with original thickness correction and with paleothickness correction related to deformation timing shows the importance of this fact.

On a similar way, the high variability in the present day heat flow in the MMVB reflects the impact of its complex evolution. Although there are some studies regarding the thermal model during the Cretaceous rift and post-rift phases, the thermal history interpretation during the compressive Tertiary phase is not as simple as an interpolation between the heat flow at the end of the Cretaceous and the present day heat flow. It is important to notice that since Eocene the strong structural deformation changed the geometric setting of the basin and subsequently, it changed the thermal regime that continue evolving through the Tertiary. We used an alternative method to calculate the Tertiary heat flow maps that contribute to have a good calibration with the paleothermometers in the MMVB.

In addition to the geometrical and thermal improvements that are presented in our approach, there is further work that is in progress in order to reduce uncertainty in other petroleum system elements. Considering that in the study area there is a limitation related to the structural restoration, we are not suggesting that this model could be better than a future one based on a regional 3D-structural model, but it is good enough to increase our confidence in supporting new exploratory opportunities in the MMVB.

Alternative workflow for 3D Basin Modeling in areas of structural complexity

Case Study from the Middle Magdalena Valley, Colombia



Román González,
Carlos Suarez & Luis Rojas

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"THE FUTURE OF BASIN AND PETROLEUM SYSTEMS MODELING"

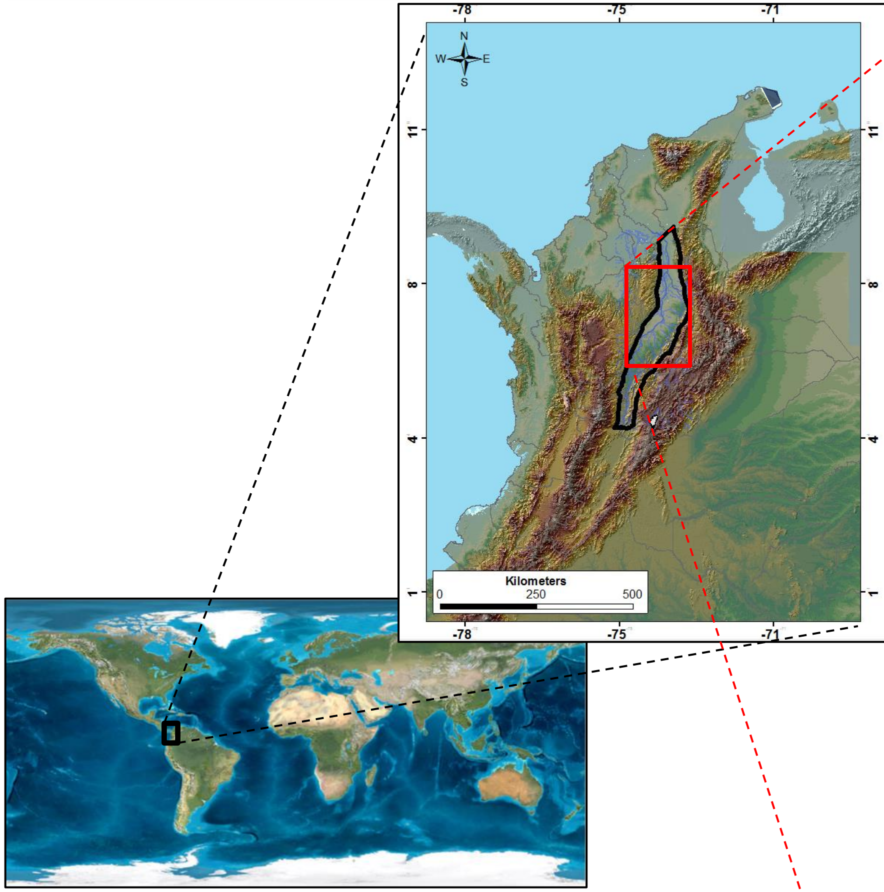
APRIL 3-8, 2016 — SANTA BARBARA, CALIFORNIA, USA

Alternative workflow for 3D Basin Modeling in areas of structural complexity

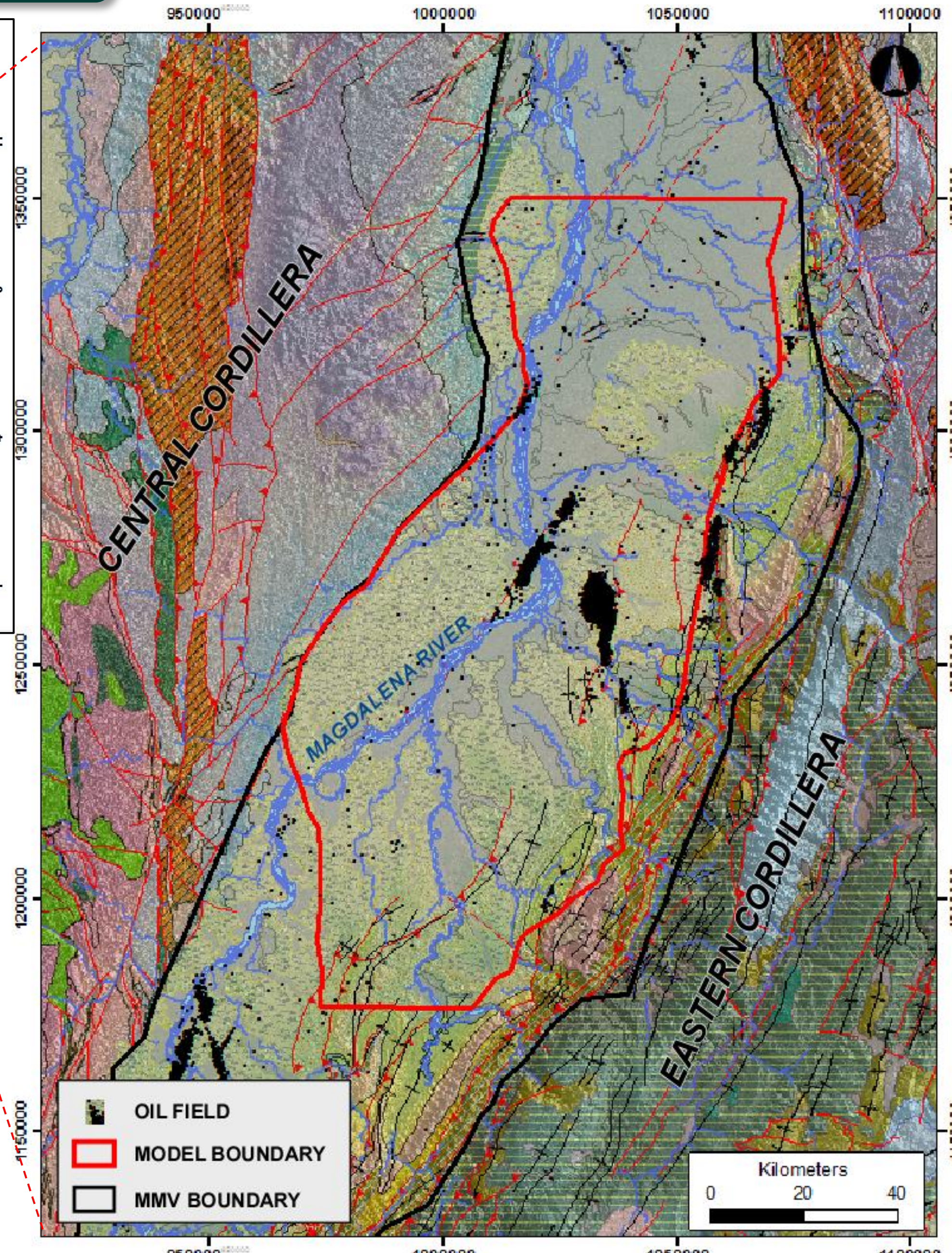
OUTLINE

- Middle Magdalena Valley (MMV) - Location and Geological Setting
- Basin modeling challenges in Structured settings
- Geometry
  - Implications in the MMV
  - Proposed workflow
- Thermal modeling
  - Implications in the MMV
  - Proposed workflow
- Conclusions

MMVB – Location



Colorado Plateau Geosystems, Inc. 2016

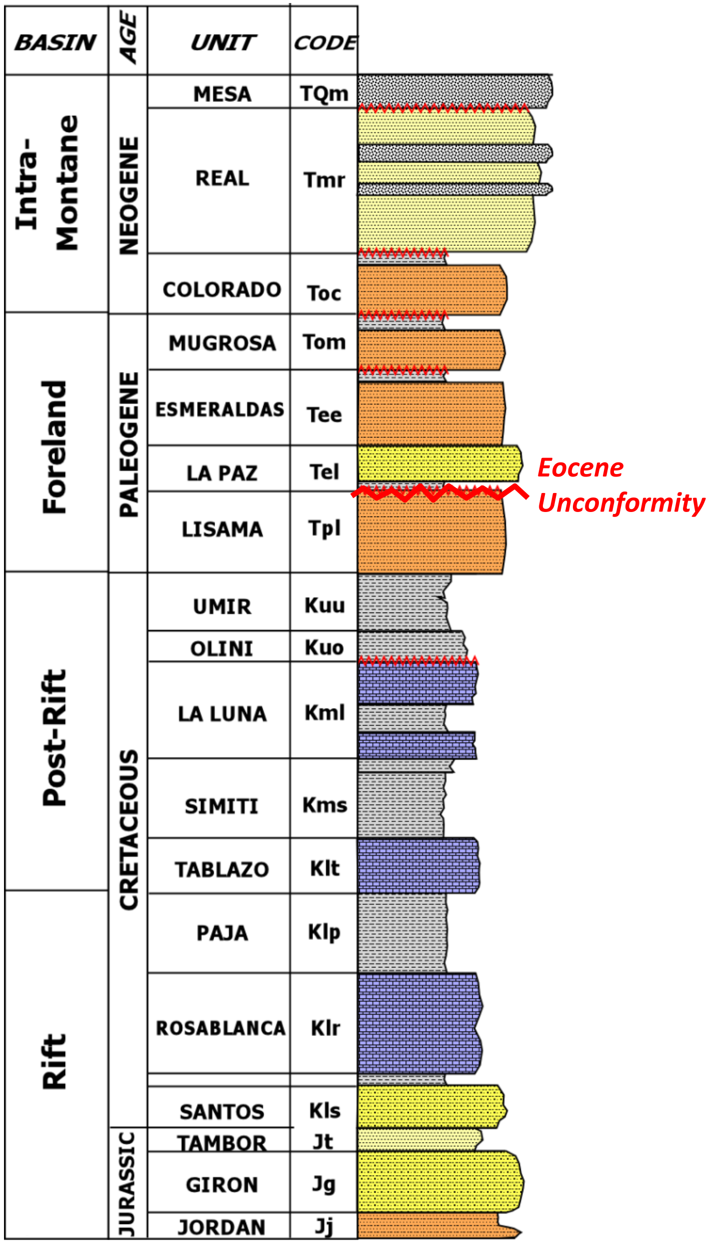


MMV

Intramontane basin

Acumulated production >> 2.000 MMBLS

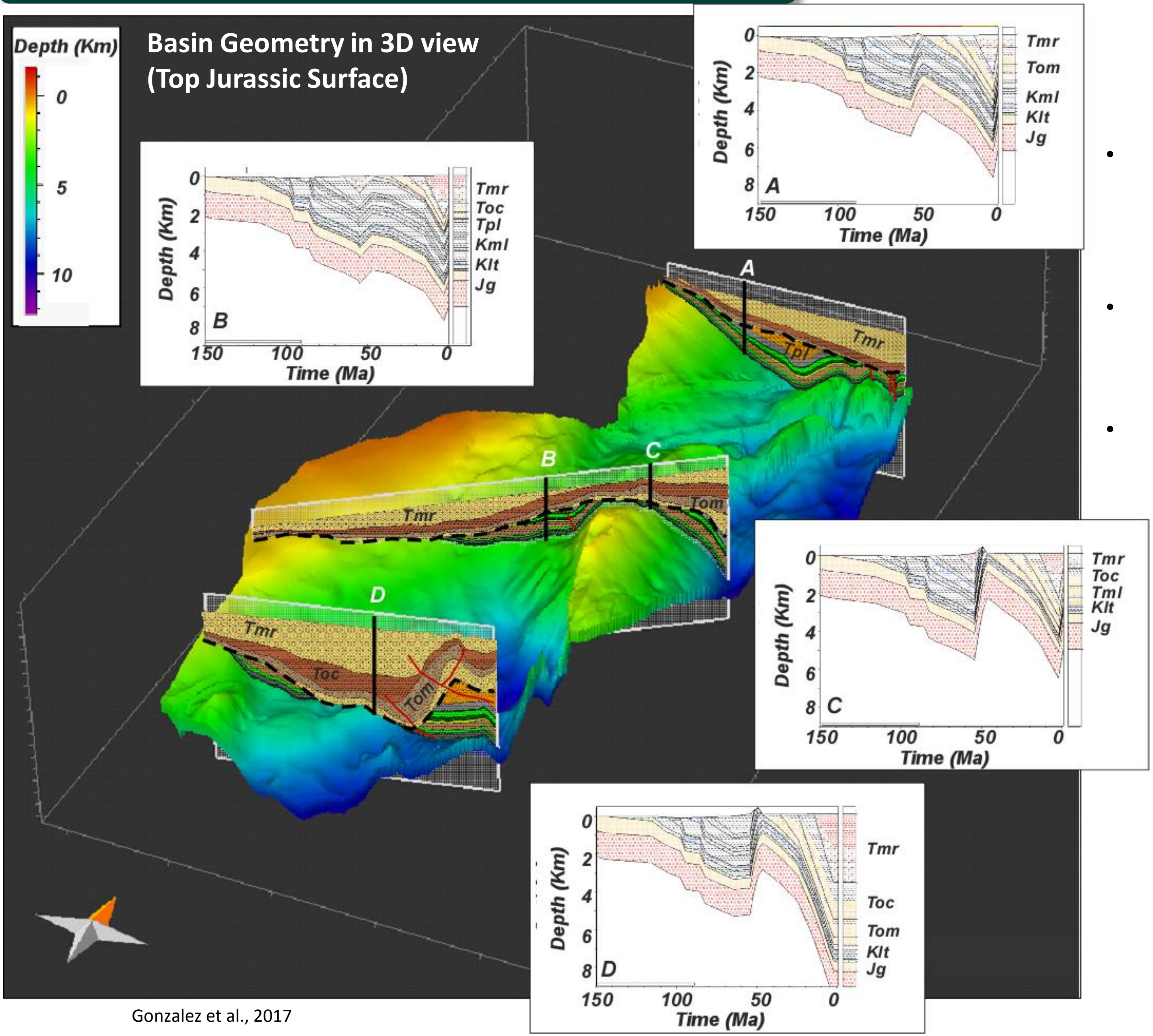
MMVB – Geological Setting



Gonzalez et al., 2017

- Reservoir and seal rocks were deposited during Paleogene and Neogene time in foreland and intramontane settings.
- The Eocene unconformity is the most prominent evidence of a tectonic inversion during Late Cretaceous-Paleogene time.
- Source rocks were deposited under rift and post-rift contidions in Cretaceous time.

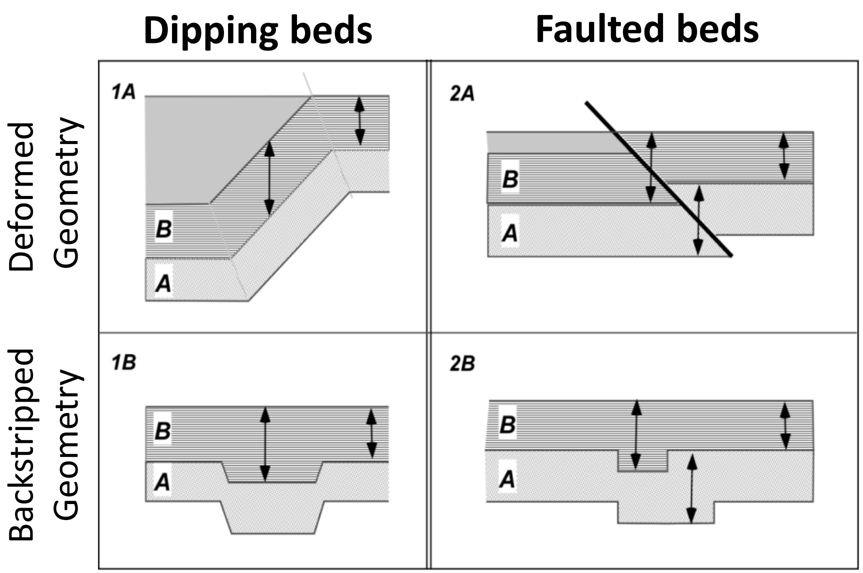
MMVB – Geological Setting



Gonzalez et al., 2017

- The Post-Eocene sequence is moderately deformed. Important lateral thickness changes.
- The Eocene unconformity is the most prominent evidence of a tectonic inversion.
- The Pre-Eocene sequence is highly deformed. A significant portion of its column was eroded by the Eocene erosion.

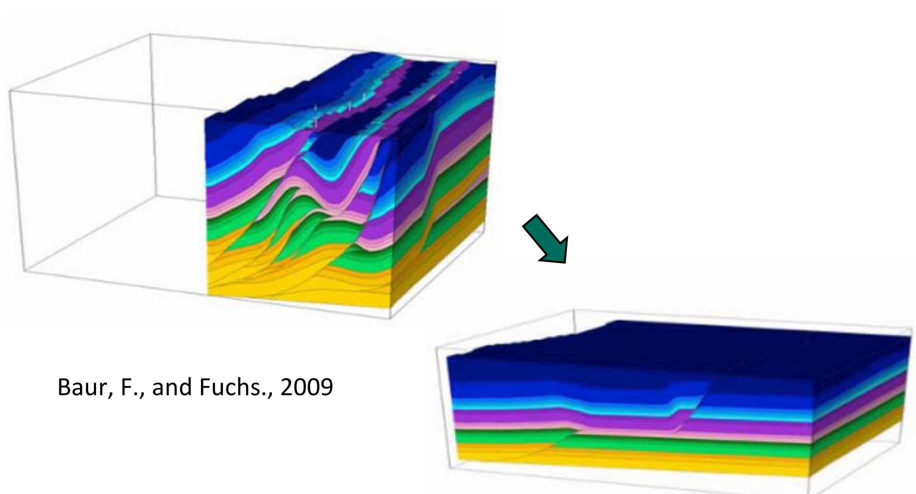
Basin Modeling Challenges - Geometry



Gonzalez et al., 2017

1) Reconstruction by means of Backstripping

- ✓ *Backstripping is the easiest and fastest method to model the burial history and paleogeometry of the basin.*
- ○ *Backstripping only works well in non-deformed basins (sub-horizontal layers)*
- ○ *In deformed settings, backstripping results in overestimated burial histories and incorrect paleo-geometries !!!*



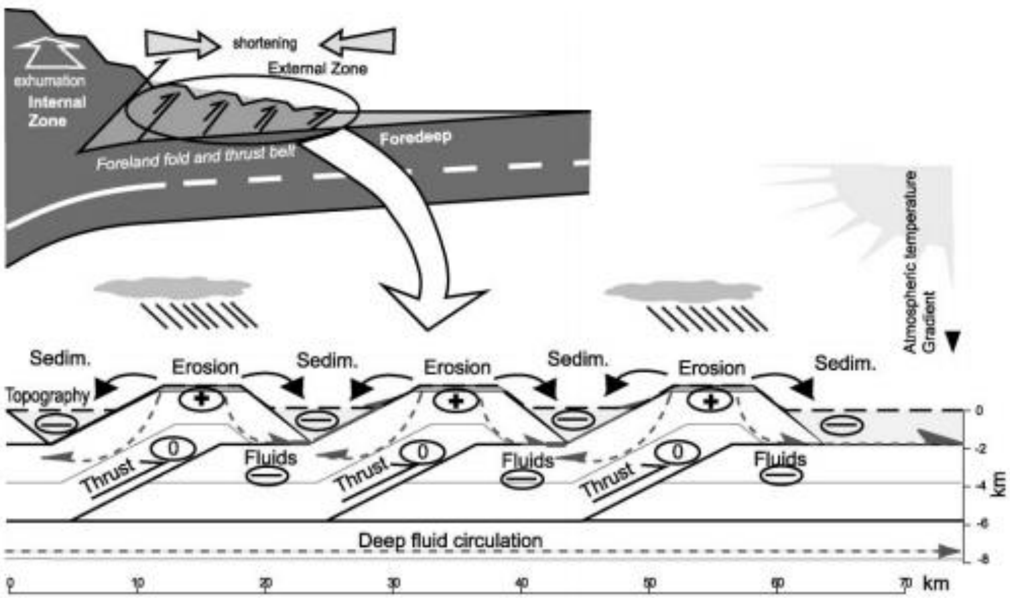
Baur, F., and Fuchs., 2009

2) Reconstruction by means of structural restoration

- ✓ *Structural restoration is a reliable method in highly deformed settings.*
- ○ *This kind of basin modeling is a procces that requieres a lot of time and resourses.*
- ○ *Testing new geometric scenarios requieres completely new models.*

Basin Modeling Challenges – Thermal Modeling

How does a thermal model evolve during compressive events?



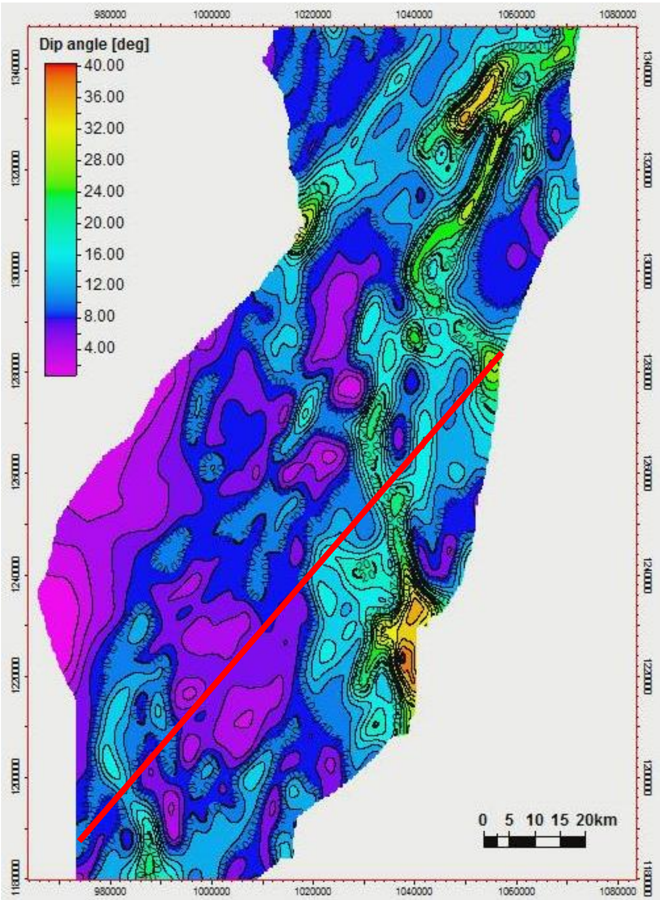
L, Husson & I, Moretti; 2000

The thermal behavior in compressive settings can be affected by:

- Topography
- Uplift
- Erosion
- Sedimentation rate
- Influx of meteoric water
- Lateral change in sedimentary thickness
- etc

Implications in MMVB – Geometry

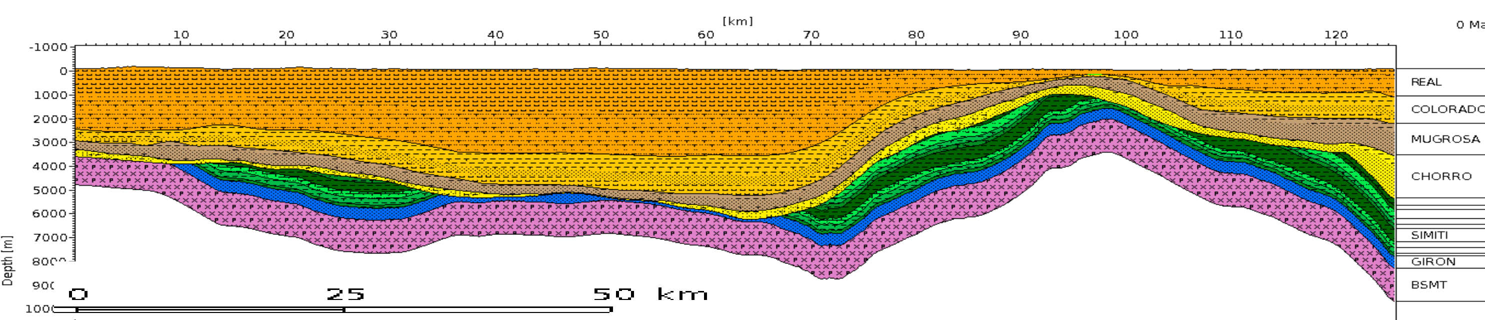
Present day Dip Map



- The Pre-Eocene sequence is highly deformed. The present day geometry is characterized by dipping and repeated faulted beds that represent problems for backstripping.

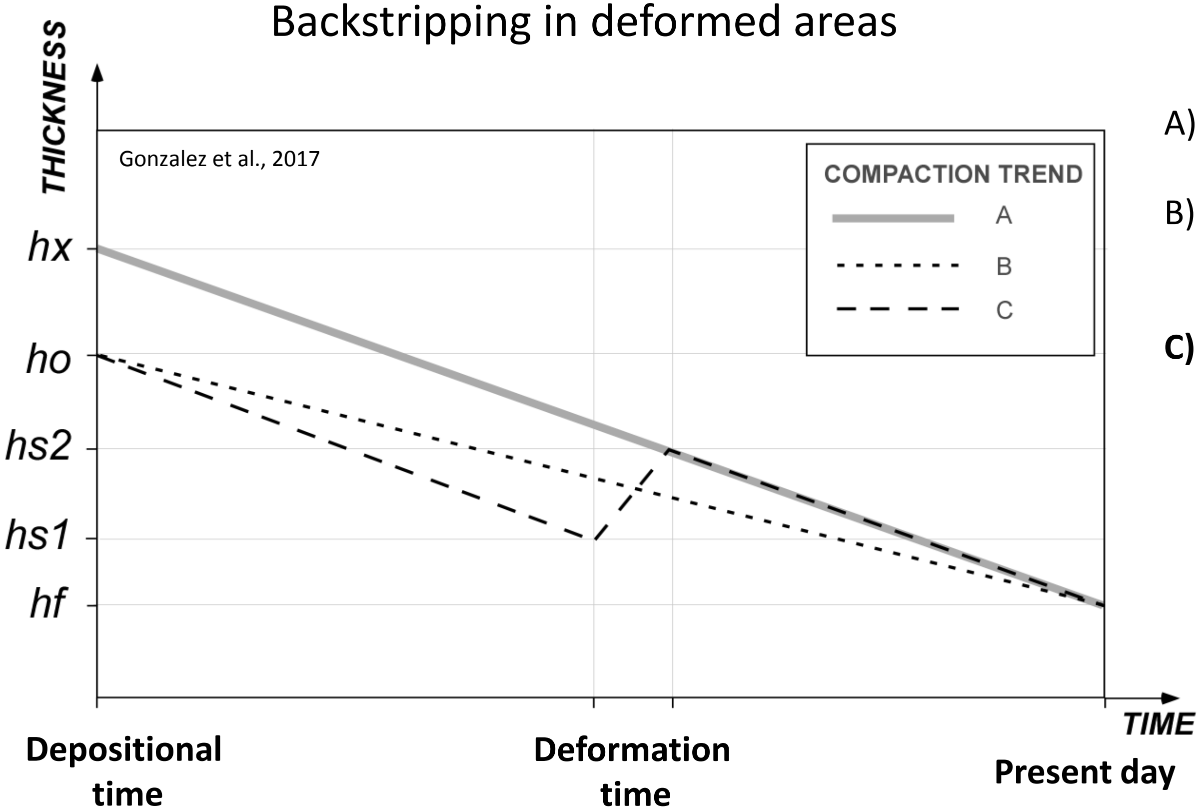
- Previous models consistently show a history of higher thermal maturity in areas of higher deformation (dips over 20°).

Modeling pitfall ???



Implications in MMVB – Geometry

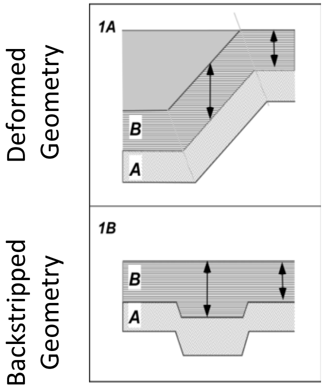
Backstripping in deformed areas



A) Simple backstripped model

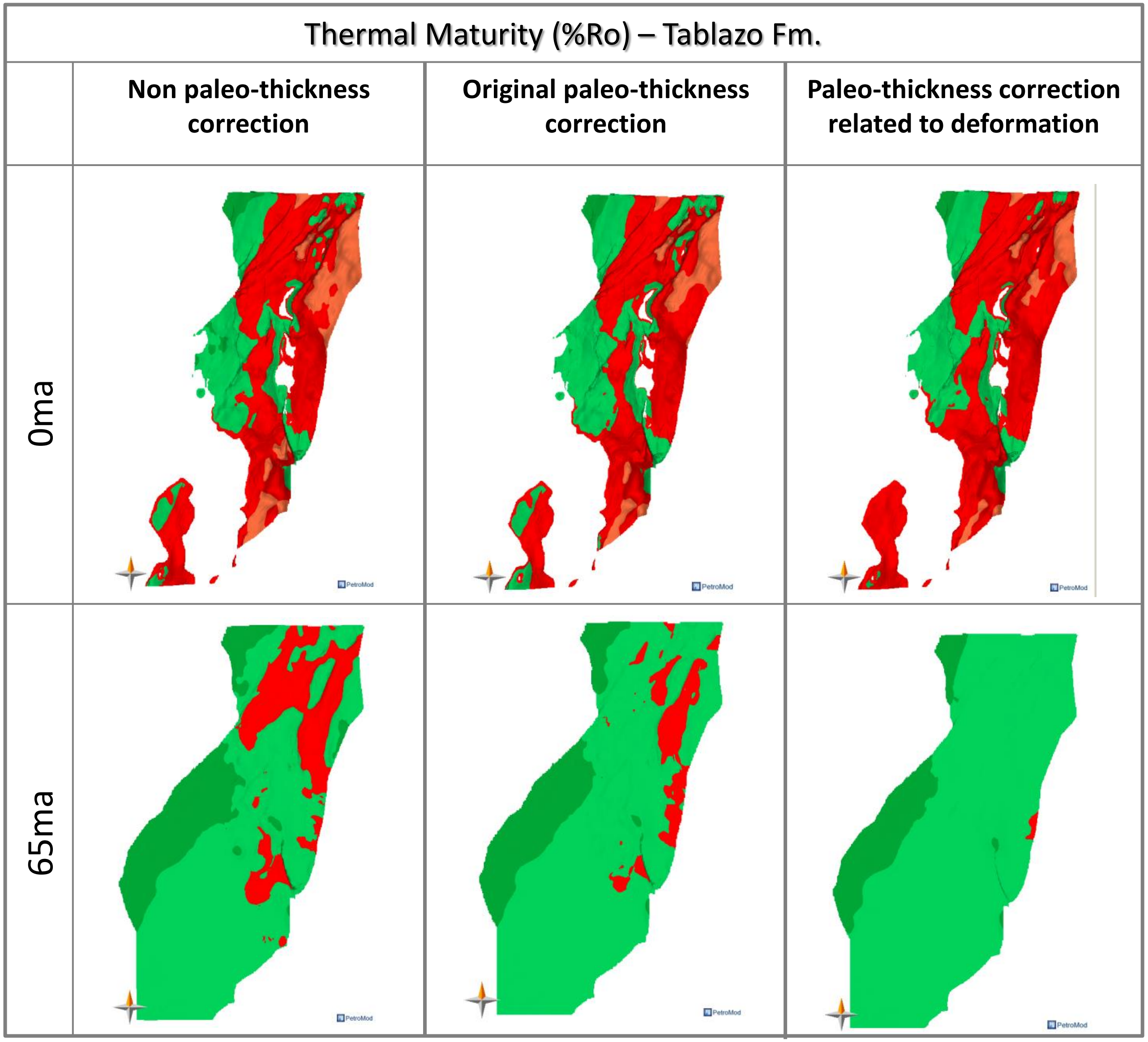
B) Backstripped model with original paleo-thickness correction

C) Backstripped model with paleo-thickness correction at deformation timing (Proposed method).



hf: Present day thickness (Structurally thickened section)
ho: Original thickness
hx: Pseudo-original thickness (Calculated from simple backstripping)
hs1: Paleo-thickness at starting time of deformation
hs2: Paleo-thickness at ending time of deformation

Implications in MMVB – Geometry

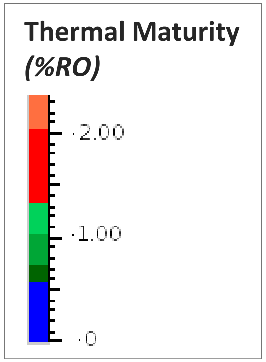


Gonzalez et al., 2017

Present day maturity is closely similar in all models.

Modeled maturity at 65ma is significantly different. Non-corrected model has higher maturity in more deformed areas

Although all models could fit calibration parameters, they reflect different basin evolutions, that can impact the basin prospectivity.



Proposed Workflow – Geometry

Workflow for Paleo-geometry correction in deformed areas

Dips > 20°

↓

Correct Original PT

↓

Run a first simulation

↓

Determine Deformation Timing

↓

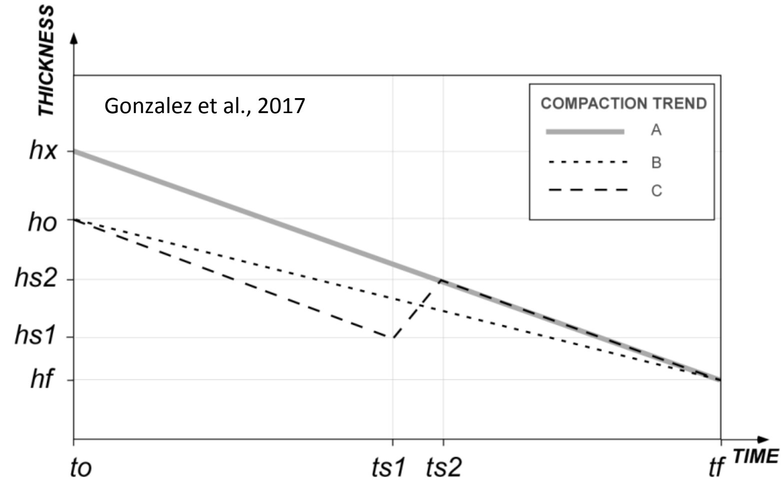
Check Maturity patterns in a Pre-deformation stage

↓

If paleo-maturity follows the present day deformation pattern

↓

Correct the geometry by tying the model to pre- and post--deformation thicknesses

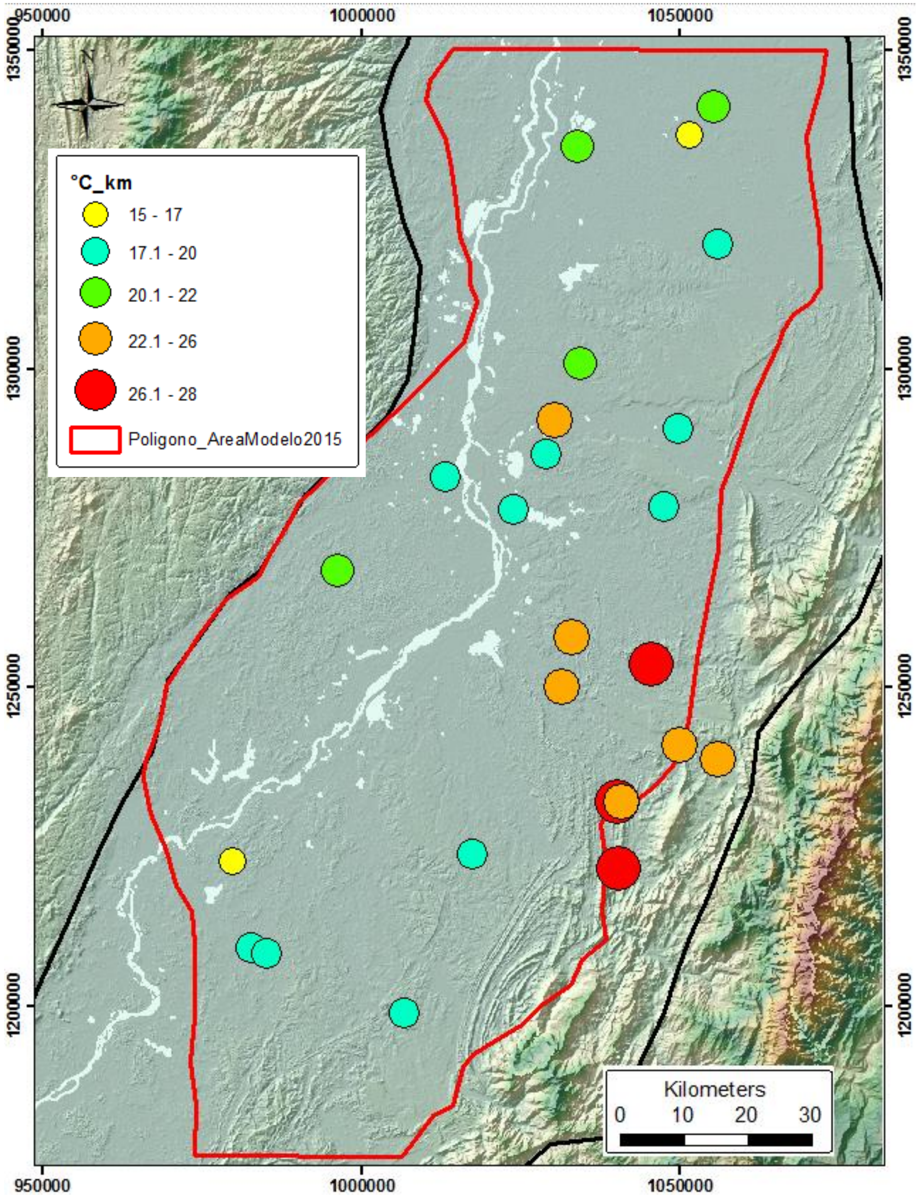


Pre-deformation thickness:
Corresponds to compacted original thickness at the pre-deformation time
(calculated from a second simulation)

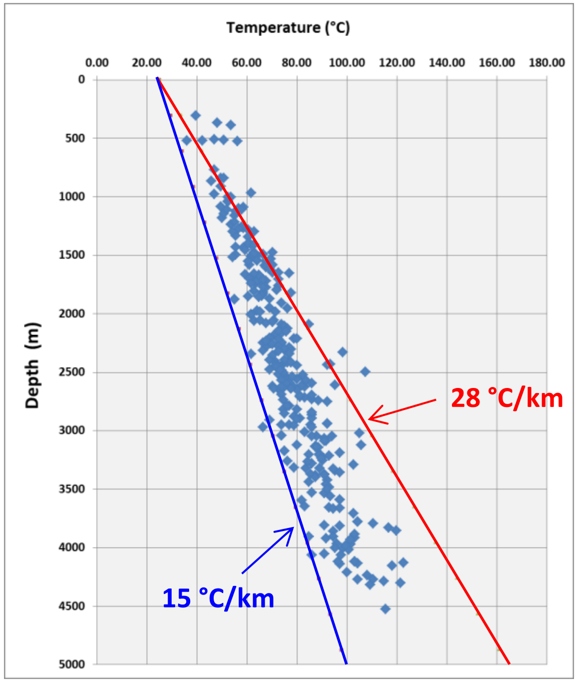
Post-deformation thickness:
Corresponds to uncompacted present day thickness at the post-deformation time
(calculated from the first simulation)

Implications in MMVB – Thermal Modeling

PRESENT DAY THERMAL GRADIENT

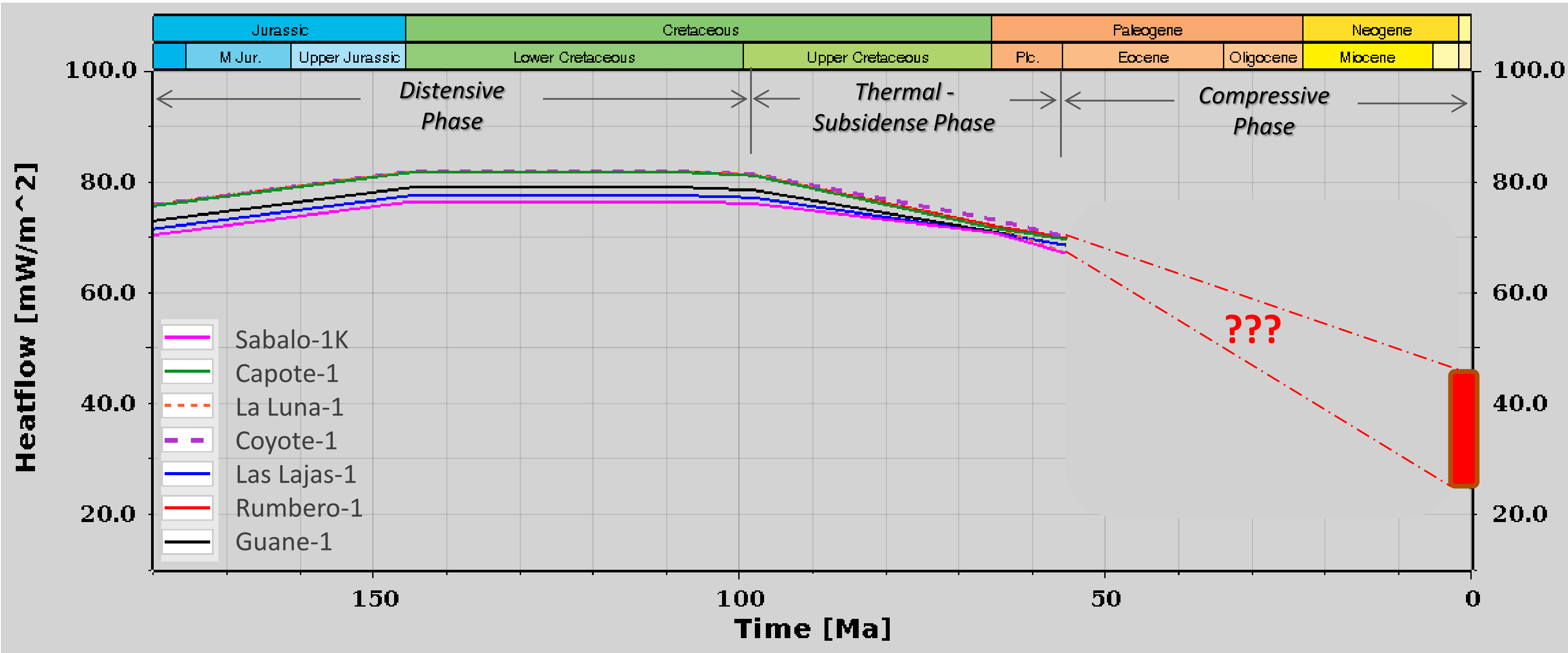


Average Thermal Gradient:
21.87 °C/km (1.18 °F/100ft)



- In the MMV there is an important spatial variation in the thermal gradient.

HEAT FLOW EVOLUTION IN THE MMV



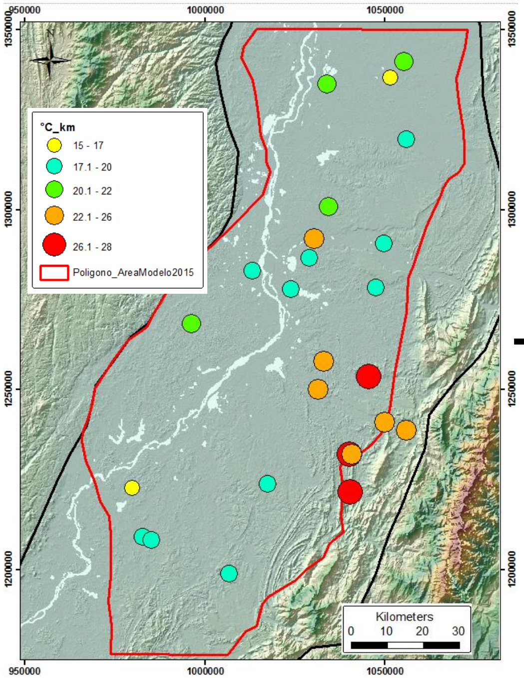
- There is an accepted thermal history during the distensive and thermal subsidence phase (Estimated by means of Mackenzie)
- The thermal development during the compressive phase is unknow.
- Present day heat flow ranges between 25 and 43 *mW/m²*

How did the heat flow model evolve during compressive events?

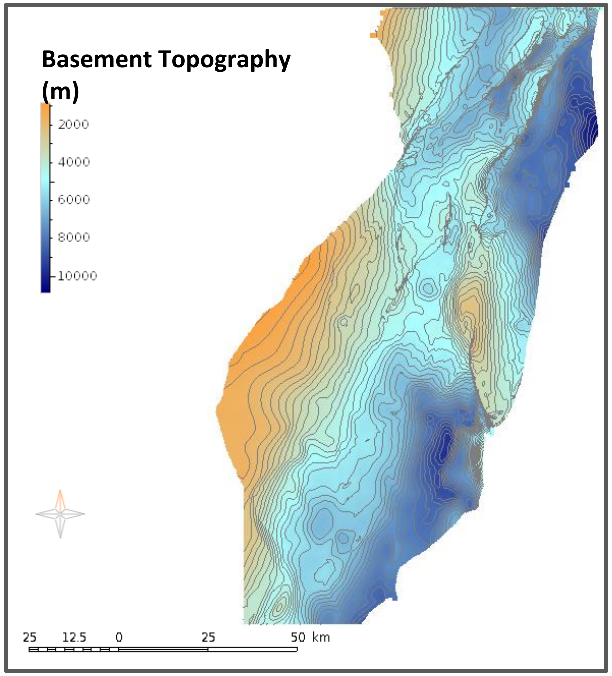
"The present is the key to the past"

Implications in MMVB – Thermal Modeling

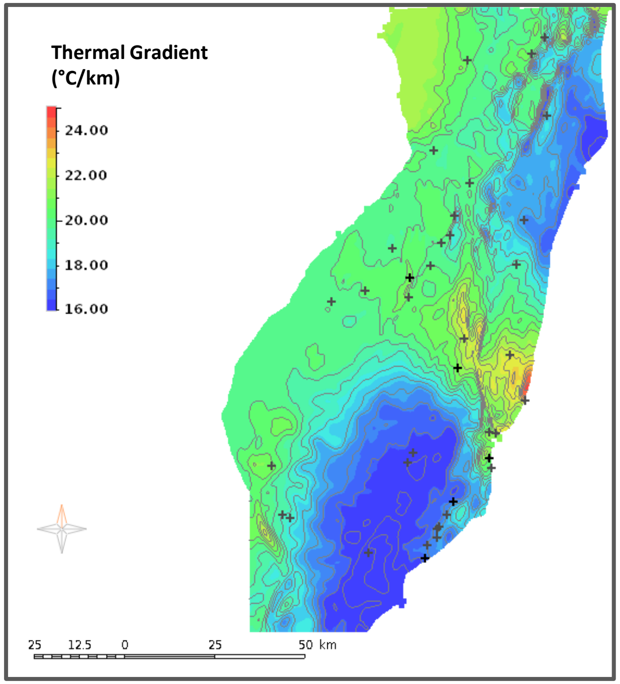
THERMAL GRADIENT DATA



BASEMENT DEPTH



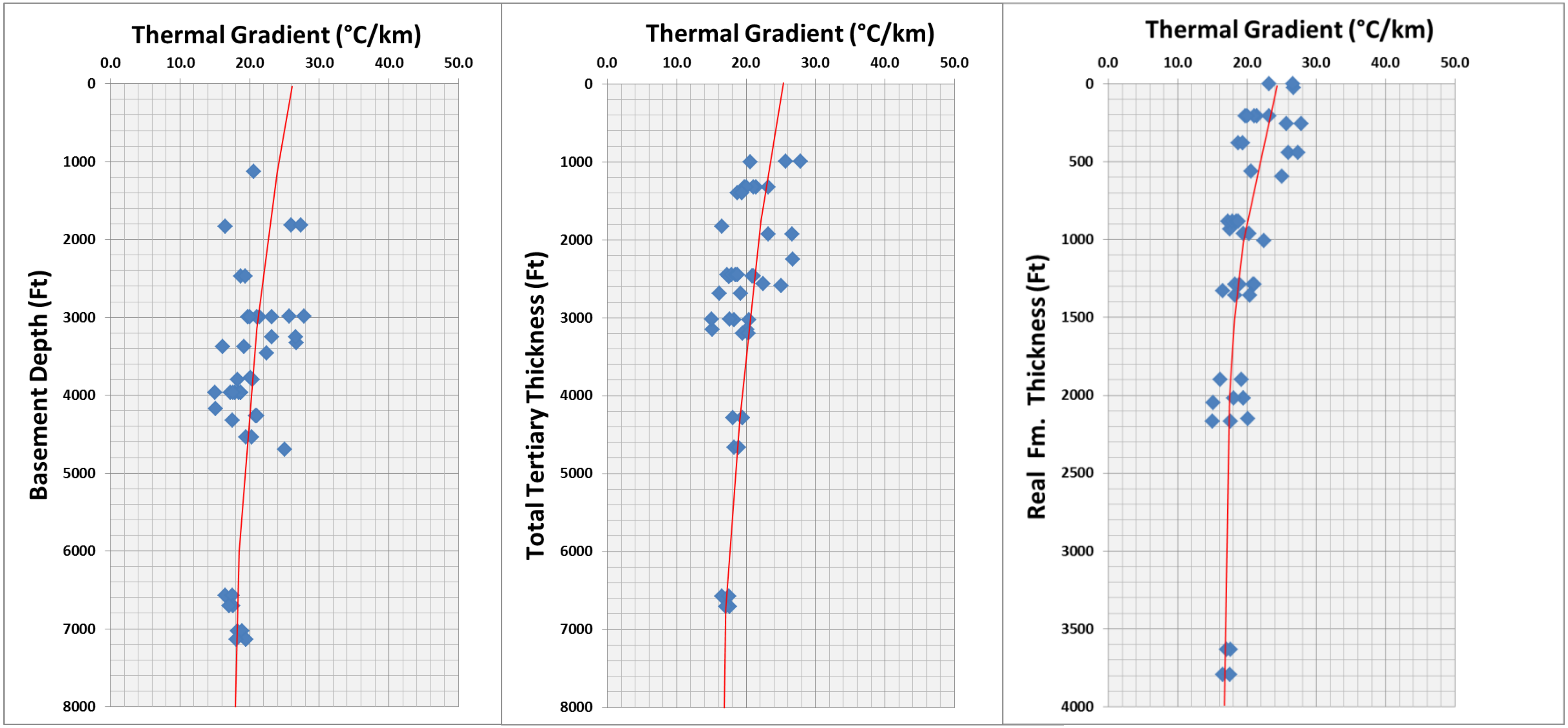
THERMAL GRADIENT MAP



- There is a positive correlation between Thermal Gradient and Basement depth.
- This similarity can be used to understand the thermal gradient distribution.

Implications in MMVB – Thermal Modeling

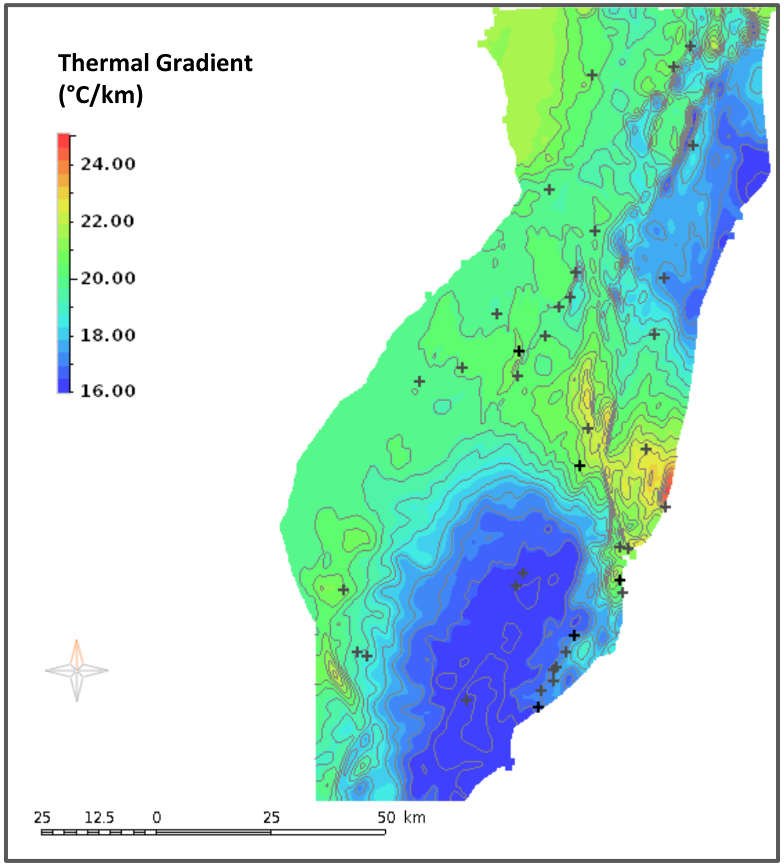
THERMAL GRADIENT CORRELATIONS



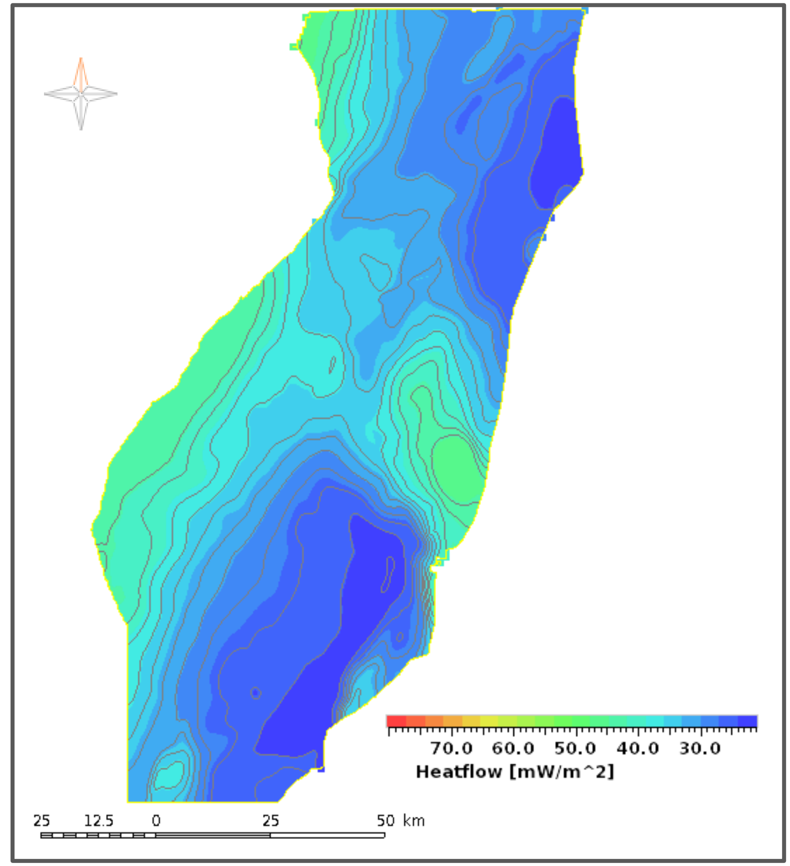
- Basement depth is not the only variable that correlates with the Thermal gradient
- A reliable thermal gradient map must consider all posible correlations.
- The obtained thermal gradient map fits measured data and is highly predictable in areas with no control.

Implications in MMVB – Thermal Modeling

THERMAL GRADIENT



HEAT FLOW



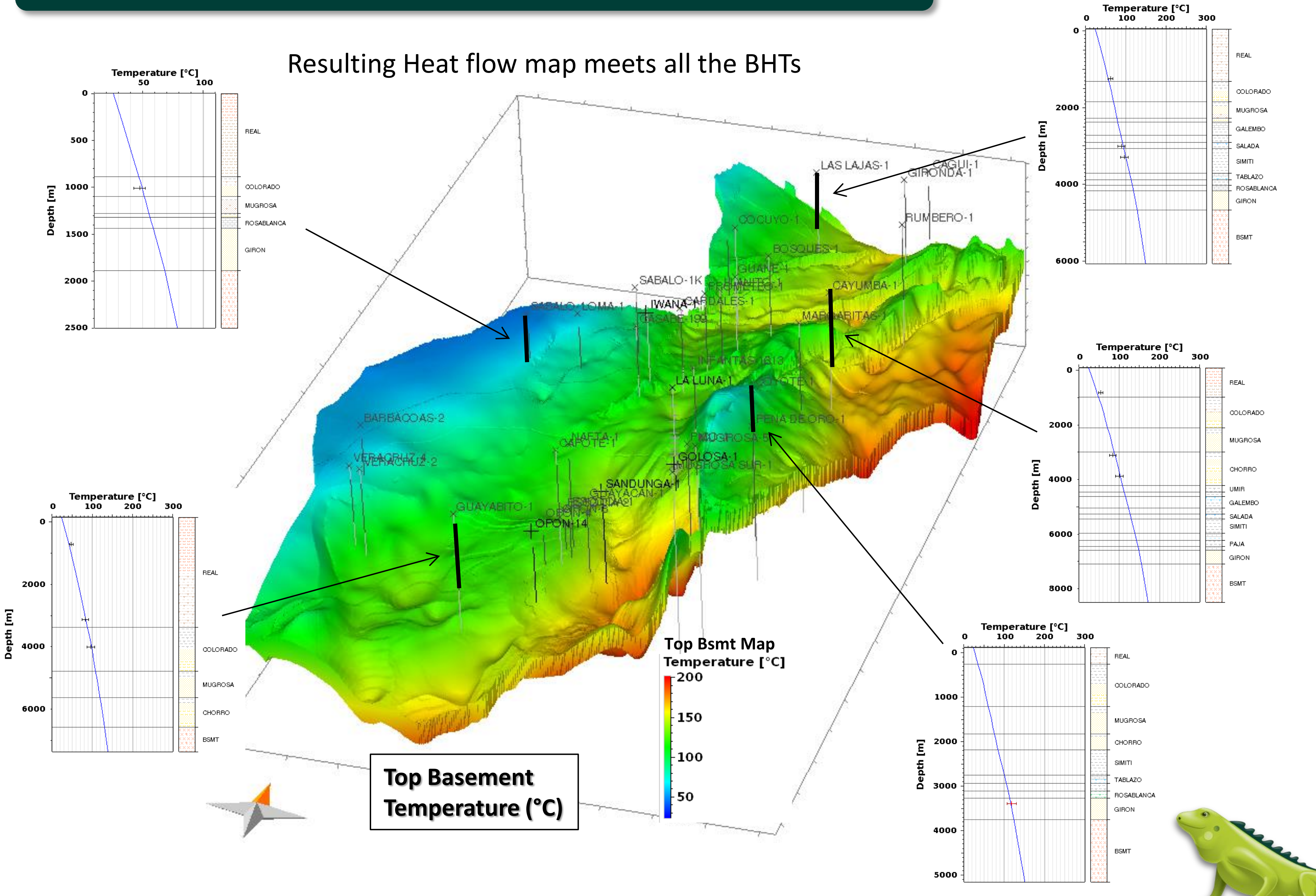
Fourier´s first law

$q = -k * \triangle T$

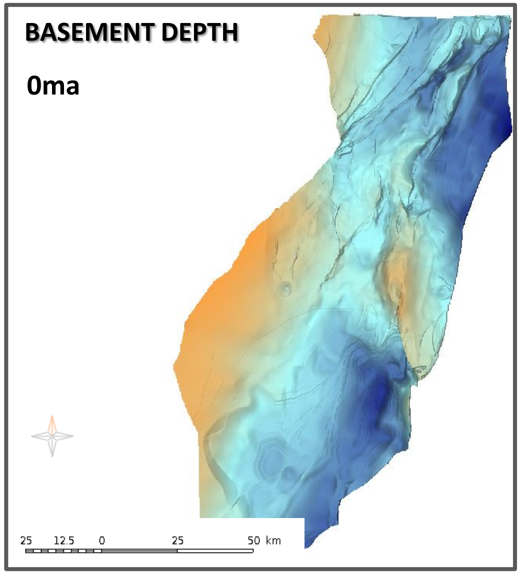
Where q is Heat flow, K is conductivity and $\triangle T$ *is* Thermal gradient.

Implications in MMVB – Thermal Modeling

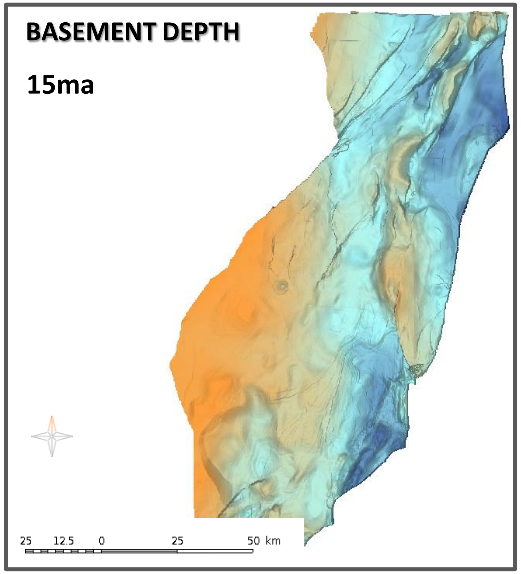
Resulting Heat flow map meets all the BHTs

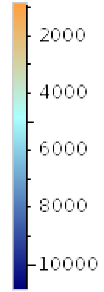


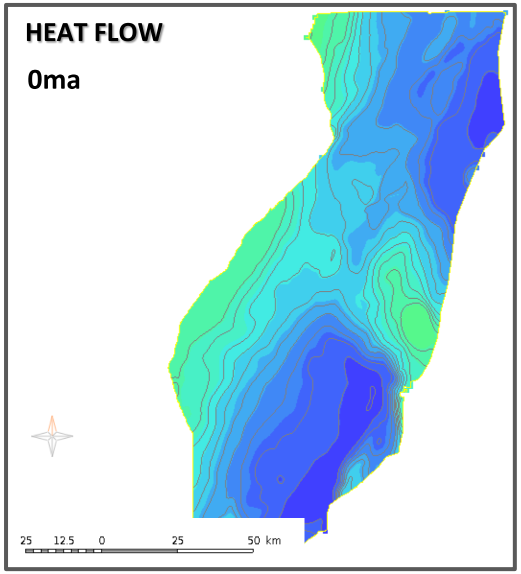
Implications in MMVB – Thermal Modeling



“The present is the key to the past”







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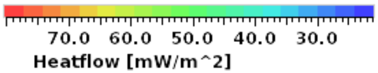
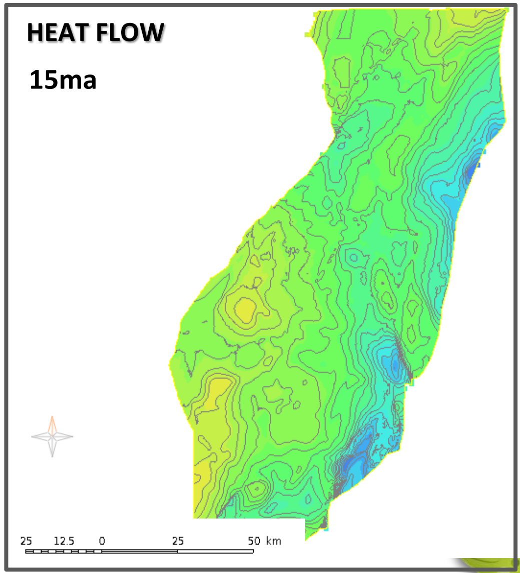
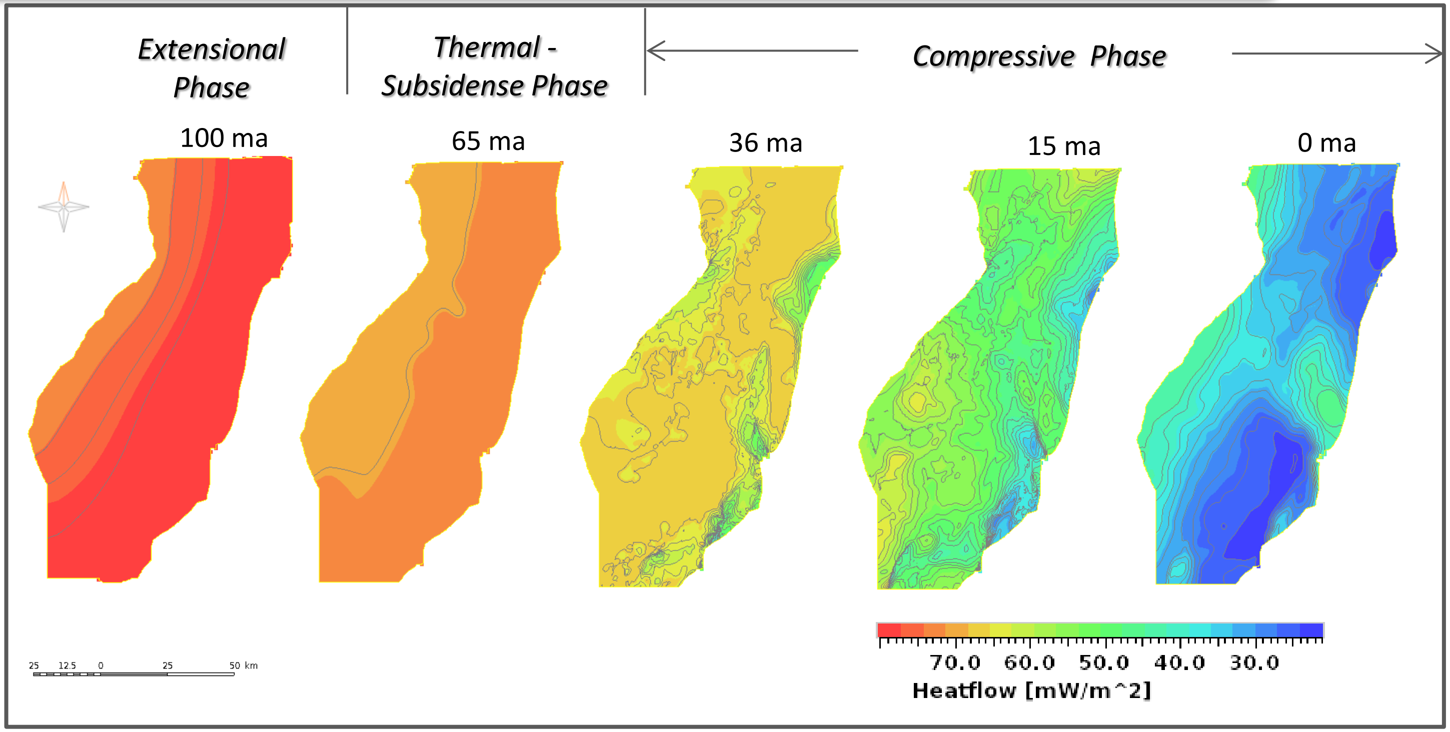


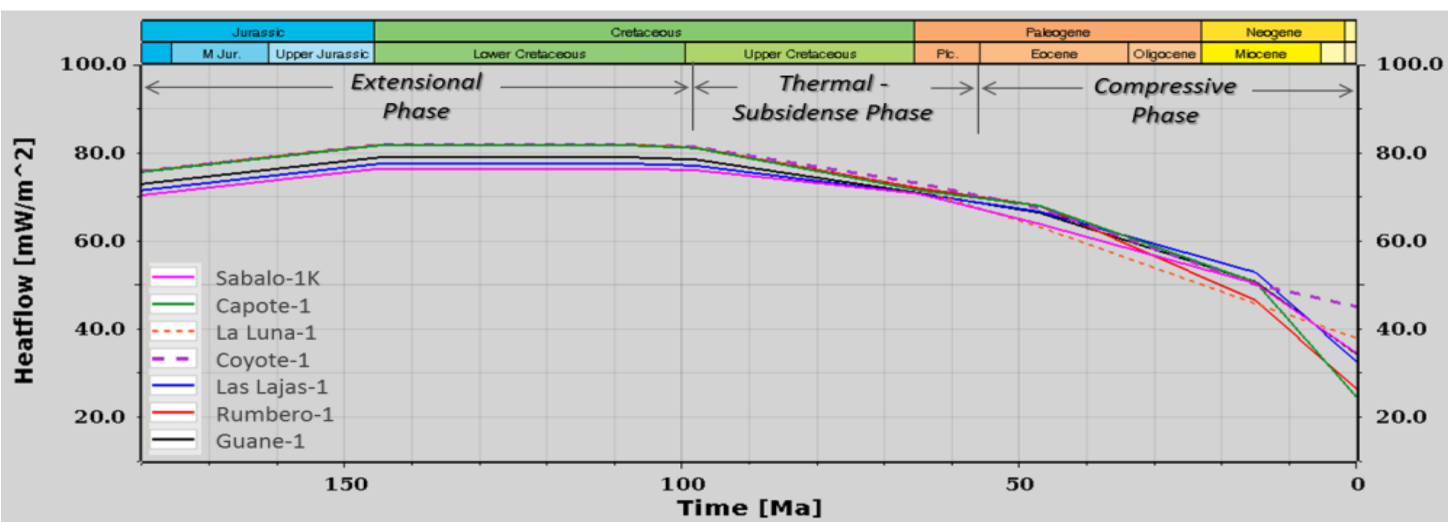


Heat flow evolution should follow a pattern of evolution similar to the correlation variables

Implications in MMVB – Thermal Modeling

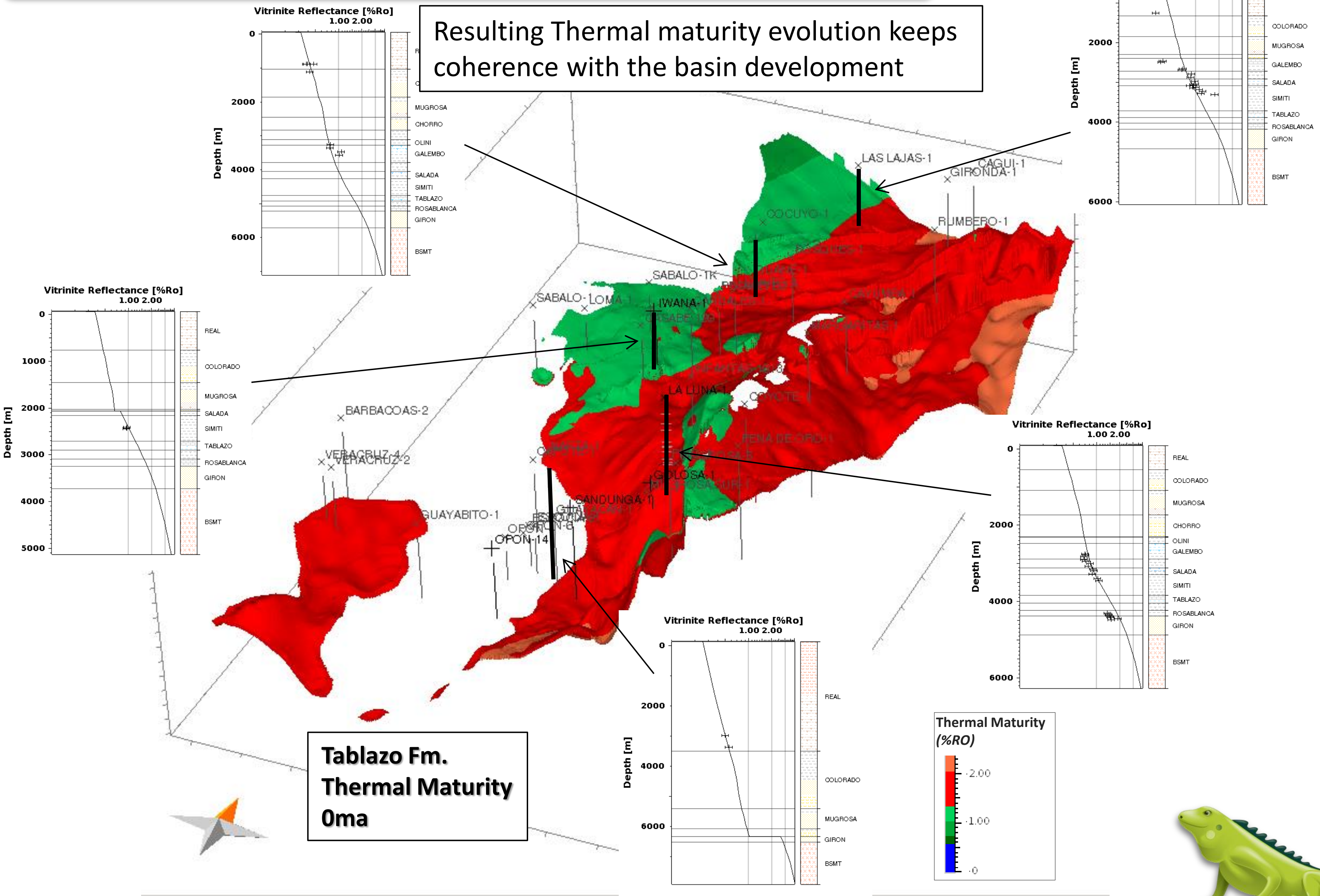


- ✓ Reliable reconstruction of Heatflow history



Implications in MMVB – Thermal Modeling

Resulting Thermal maturity evolution keeps coherence with the basin development



Tablazo Fm. Thermal Maturity 0ma

Proposed Workflow – Thermal Modeling

Workflow for an area where tectonic events have disturbed the current thermal model

Build a thermal gradient database

↓

Simulate a preliminary model

↓

Identify parameters that have correlation with the thermal gradient

↓

Calculate thermal gradient and heat flow maps

↓

Simulate a new model to check calibration for present day temperatures

↓

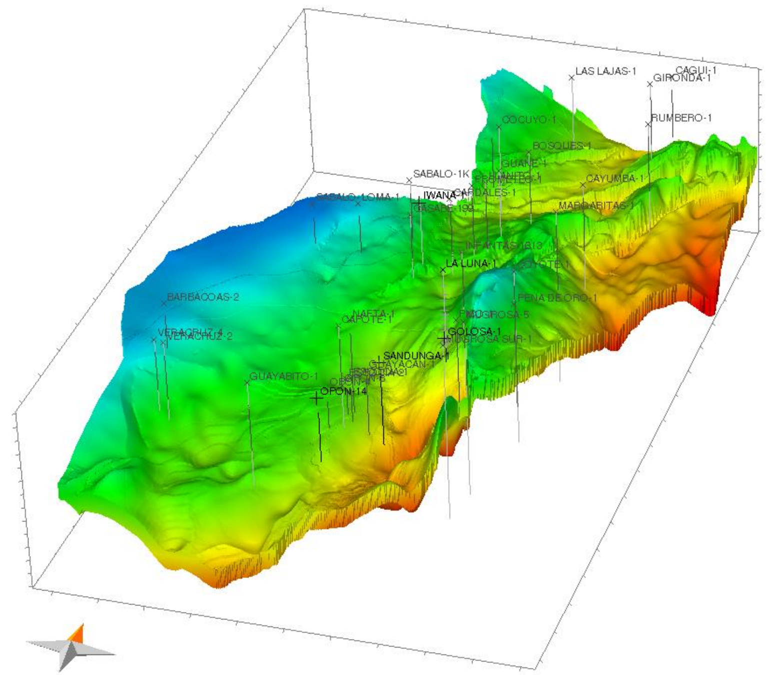
Define control points in time to create paleo-heat flow maps

↓

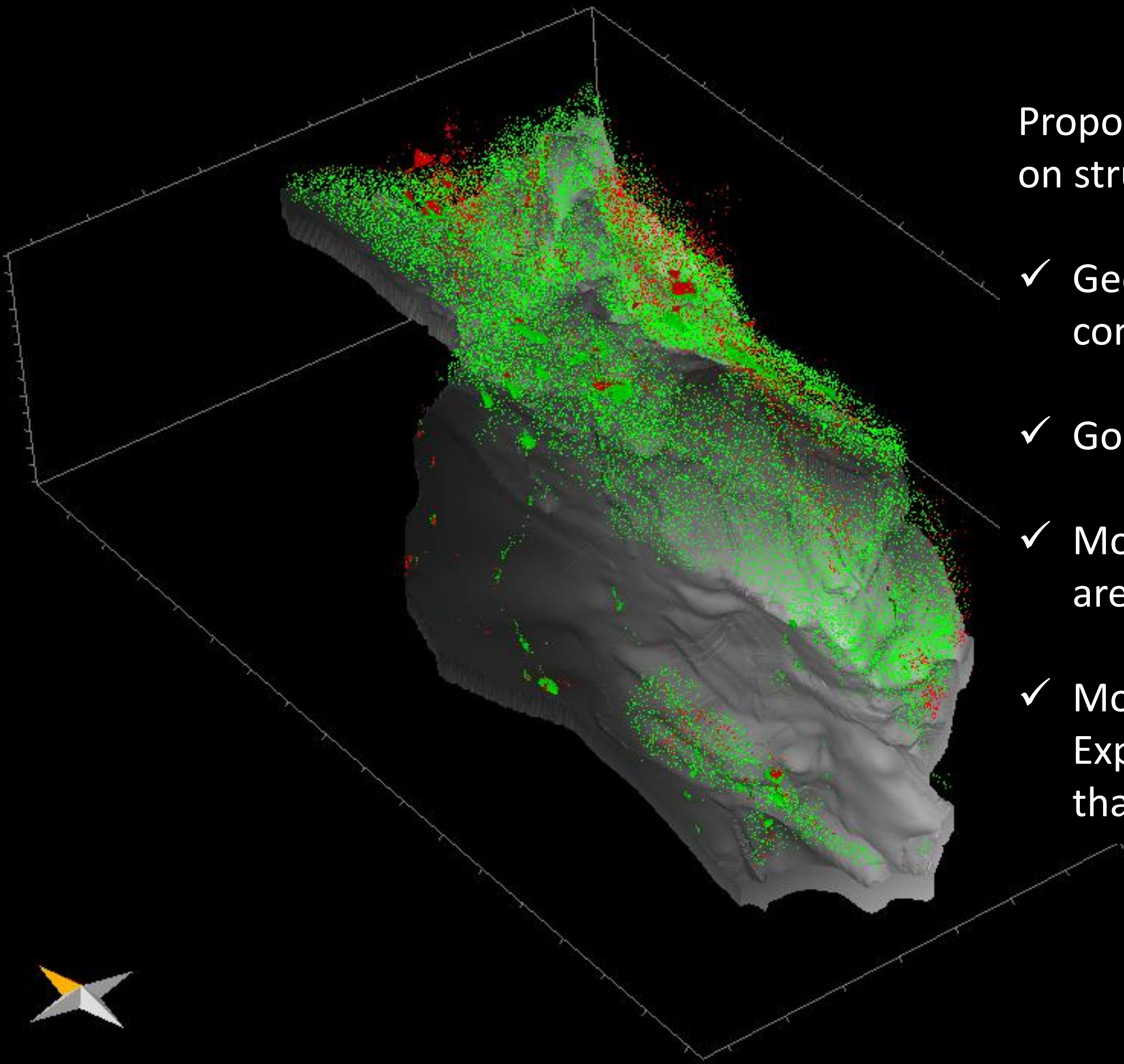
Calculate the relative change of correlation parameters at that time

↓

Calculate paleo-heat flow maps → Simulate a model to check calibration with paleothermometers



Alternative workflow for 3D Basin Modeling in areas of structural complexity



CONCLUSIONS

Proposed workflow for basin modeling on structured settings can provide:

- ✓ Geometrical and thermal evolution consistent with tectonic history
- ✓ Good fit to Calibration parameters
- ✓ More reliable thermal predictions in areas without data
- ✓ More convincing Generation, Expulsion and Migration histories than non-corrected models

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