CHAPTER 7

BASIN MODELING – TEMIS FLOW 3D

CHAPTER 7.1

BASIN MODELING – 3D BLOCK BUILDING

Play Fairway Analysis Offshore SW Nova Scotia
TEMIS FLOW 3D® Basin Modeling – INTRODUCTION

→ Objectives:

- Active petroleum systems description
- Petroleum system chart definition
- Source rocks potential evaluation at the scale of the whole basin
- **In place HC volumes estimation**

→ Tools:

- The basin modeling software Temis Flow 3D®
- Migration tools Trap Charge Assessment (Ray Tracing method)

→ Input data:

- Seismic data (chrono-structural interpretation in Depth)
- Sedimentological data (Dionisos® results and other synthesis)
- Geological synthesis (on geohistory, petrophysics, geochemistry, etc.)

Table of Contents

(1) Basin Modeling - 3D Block Building
Building of the 3D geological model. Compilation of structural data, sedimentological data, geochemical data, etc.

(2) Maturity / Expulsion Simulation
1st modeling phase with Temis Flow 3D® with a first scenario.
Modeling of the 3D block through the time (maturity and expulsion, migration not computed).
Analysis of Temis 3D® results for the definition of source rocks potential.

(3) Migration Simulation
2nd modeling phase with Temis Flow 3D® on the first scenario.
Modeling of the 3D block through the time with HC Darcy migration using Visco calculator.
Redistribution of HC accumulations by intervals using Trap Charge Assessment tool.

(4) Hot Spot Scenario
Modeling of the 3D block through the time (maturation) using a second scenario including an hot spot.

(5) Conclusions

Resolution of TEMIS FLOW 3D Blocks used for this study

→Reference 3D Block, from seismic interpretation:

- 351*199 meshes
- mesh resolution 1 * 1 km
- 10 layers (11 horizons)

→ 3D Block for Temis / Maturity Modeling:

- 351*199 meshes
- mesh resolution 1 * 1 km
- 36 layers (37 horizons)

→ 3D Block for Migration Modeling

- 158*99 meshes
- mesh resolution 2 * 2 km
- 36 layers (37 horizons)

5 STRATIGRAPHIC INTERVAL and 5 SOURCE ROCKS are studied:

STRATIGRAPHIC INTERVAL	*SOURCE ROCKS*
Cenomanian-Albian (K101-K94)	APTIAN SR (~K124)
Albian-Barremian (K130-K101)	VALANGINIAN SR (~K136)
Barremian-Tithonian (J150-K130)	TITHONIAN SR (~J150)
Tithonian-Callovian (J163-J150)	CALLOVIAN SR (~J163)
Early-Middle-Jurassic (J200-J163)	LOW JURASSIC COMPLEX SR (~J196)

Stratigraphic chart in the Reference 3D Block

11 horizons provided by geophysicians are used in the model. Other horizons correspond to subdivisions with limited geological constraints (Table 1).

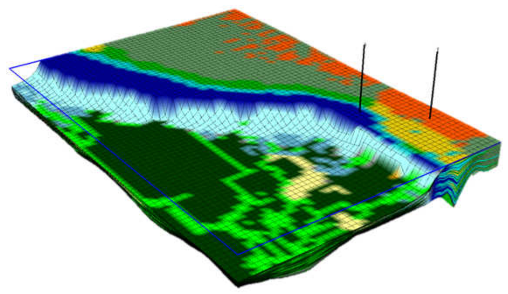
Age (horizon)	Horizon	Top Source Rocks	Seismic Horizons	Horizon Color
0	Sea bottom		Yes	
14,5	Miocene		Subdivision	
29	Oligocene Unconformity		Yes	
50	Eocene		Yes	
70	Upper Cretaceous		Subdivision	
94	Cenomanian Unconformity		Yes	
97	Cenomanian		Subdivision	
99	Cenomanian		Subdivision	
101	Albian-Logan Unconformity		Yes	
106	Albian		Subdivision	
112	Aptian Logan-Cree		Subdivision	
124	Top Aptian SR		10m Thickness	
125	Barremian		Subdivision	
130	Barremian		Yes	
131,5	Barremian		Subdivision	
133,5	Hauterivian		Subdivision	
134,5	Hauterivian		Subdivision	
136	Top Valanginian SR		10m Thickness	
137	Top BCU		Yes	
140	Valanginian		Subdivision	
148	Berriasian		Subdivision	
150	Top SR Tithonian		Yes	
151	Top Tithonian		Subdivision	
154	Upper Jurassic Ind.		Subdivision	
157	Kimmeridgian		Subdivision	
160,5	Callovian		Subdivision	
163	Top SR Callovian		Yes	
165	Scatarie		Subdivision	
170	Bajocian		Subdivision	
175	Aalenian		Subdivision	
180	Toarcian		Subdivision	
185	Toarcian		Subdivision	
190	Pleisbachian		Subdivision	
195	Sinemurian		Subdivision	
196	Top Low Jurassic Complex SR		20m Thickness	
197	Top Autochtonous Salt		Yes	
220	Top Basement		Yes	

Table 1: Horizons and SR used to build the 3D Block.

SEISMIC INTERPRETATION – STRUCTURAL MAPPING

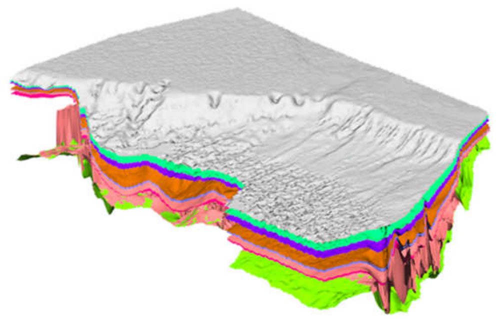
SOUTH WEST NOVA SCOTIA EXTENSION - CANADA - June 2015

Dionisos® Sedimentary Facies Maps



→ Mesh Refining (Dionisos® grid resolution 4 * 4 km).
→ Conversion in petrophysical facies.
→ Definition of petrophysical properties with:
- Temis® default lithologies library
- Log and core data (porosity, permeability, etc.)
- Temperature and pressure calibration

Structural Maps from Seismic Interpretation



→ Correction and smoothing.
→ Identification of salt bodies.
→ Additional subdivisions for:
- Reservoirs (according Dionisos®)
- Source rocks (with effective thickness maps
- Refining of sedimentary sequences (Automatic subdivisions proportional to the age)
- Technical subdivisions (refining time steps)

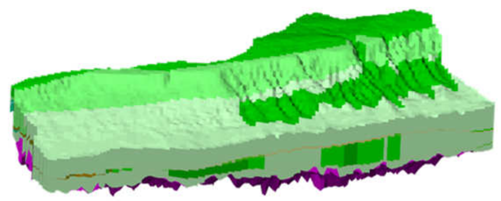
→ Restoration through time.

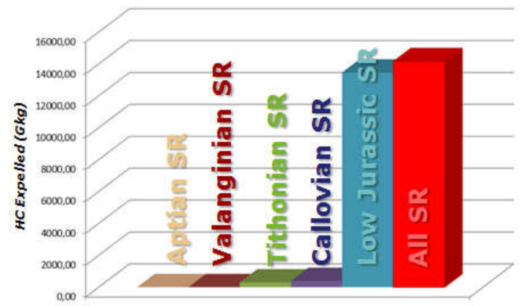
Geological Data

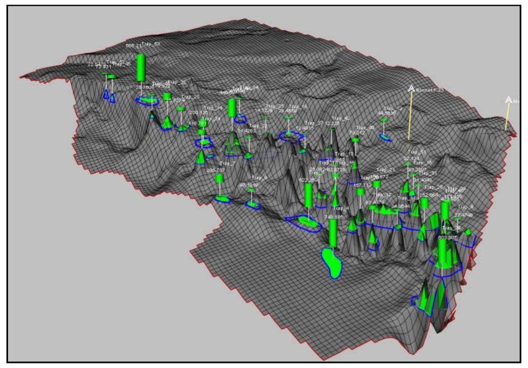
→ Geological context
→ Geological history
→ Deep geophysics
→ Geochemical data
→ Well log data
→ Petroleum field data

PFA 2011

→ Coherency between the two models (data and results)
→ Crust model and rifting

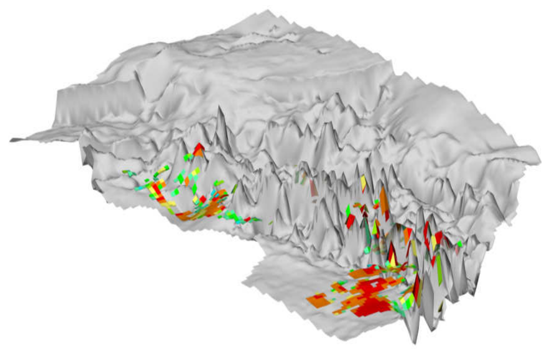




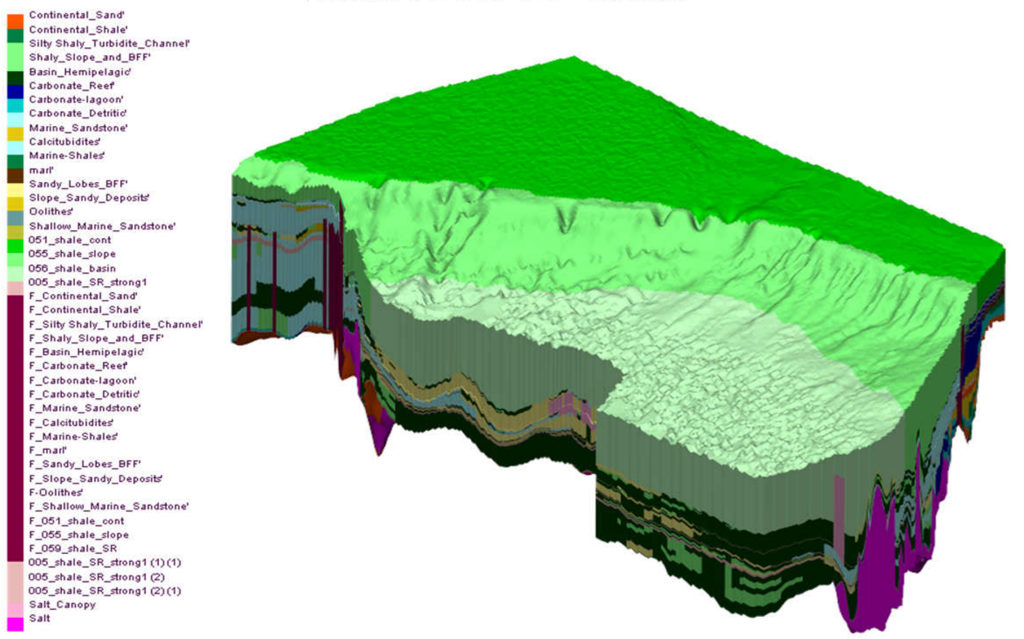


Source Rocks Parameter
- Kerogens types
- Chemical kinetics
- TOC

Thermal boundaries
- Surface Temperature history
- Thermal basement (lithosphere modeling)
- Rifting history



TEMIS FLOW 3D® Block



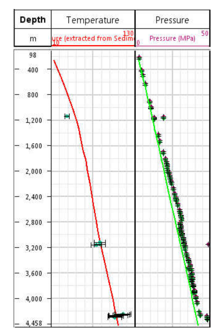
*GRID RESOLUTION = 1 * 1km*

PRESSURE / TEMPERATURE / MATURITY MODELING

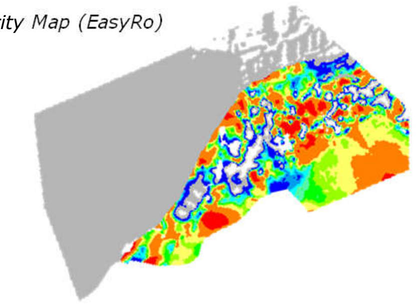
Calibration Phase
- Pressure
- Temperature
- Vitrinite

SR Modeling
- Present day maturity level
- Maturity history
- Expelled volumes

Calibration Plot



Maturity Map (EasyRo)



1st Modeling Phase

HCs MIGRATION MODELING

Traps and HCs Volumes Estimation
- Complete Darcy Migration taking into account all the model on an upscaled version (2* 2km).
- Redistribution of HCs volumes with the Trap Charge Assessment tool.
- HCs in place (mass, volume, composition, .etc…)

2nd Modeling Phase

Sediment Model Building

- Model skeleton was build using depth interpreted horizons corrected from crossings and canopies.
- Layering was done according Dionisos ® model (key intervals with specific lithofacies distribution) and to keep a moderate thickness between horizons.
- Source Rocks thicknesses were taken from PFA2011 model.
- Dimension : 1 * 1km
- Number of cells : 315I * 199J *36K = 2 193 957
- The interval from J150 (Tithonian) to basement has been shifted to +300m compared to PFA2011 due to depth conversion model.

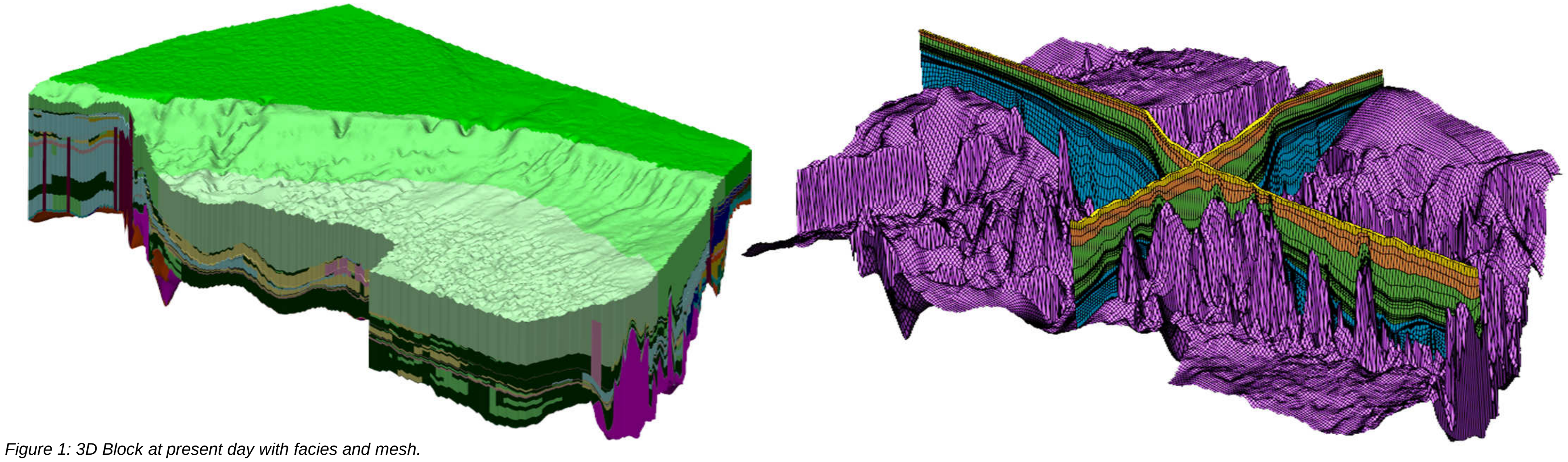


Figure 1: 3D Block at present day with facies and mesh.

Salt Restoration

- Salt restoration was done according tectonic evolution (Weston et al., 2012), sedimentation and paleobathymetry (Figure 2).
- Salt volume is approximately considered constant through time (2.8-2.5*E13 m3).
- Basement geometry was smoothed through time.
- Canopies formation starts at 101 My and ends at 50 My where we assume there is no more salt movement.

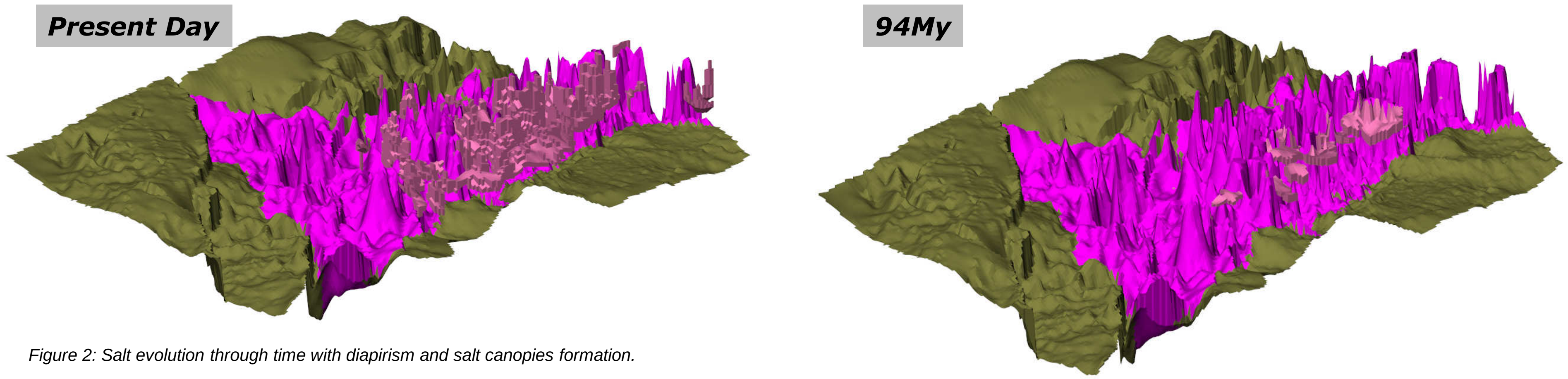
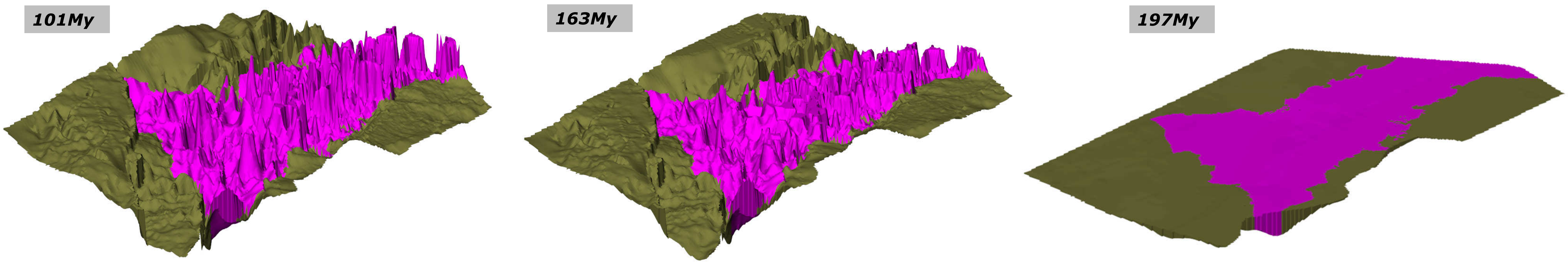
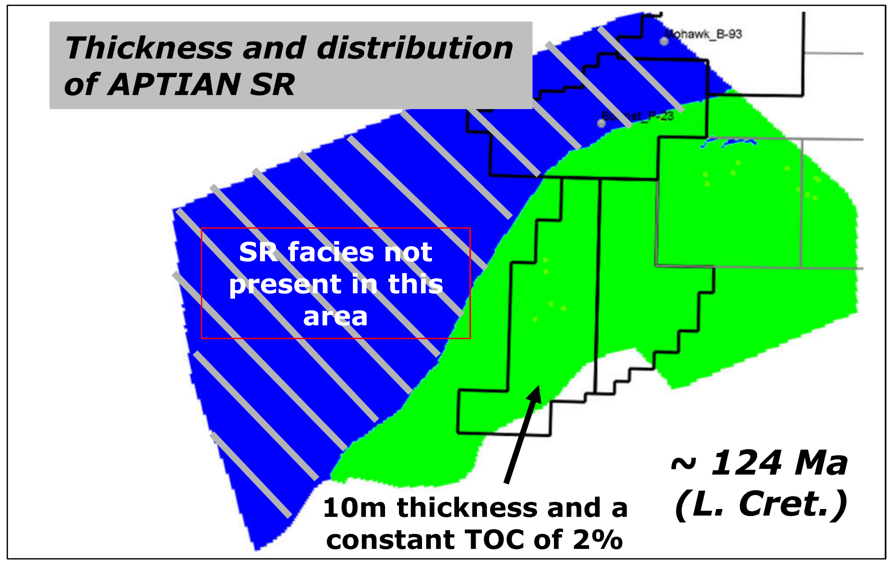
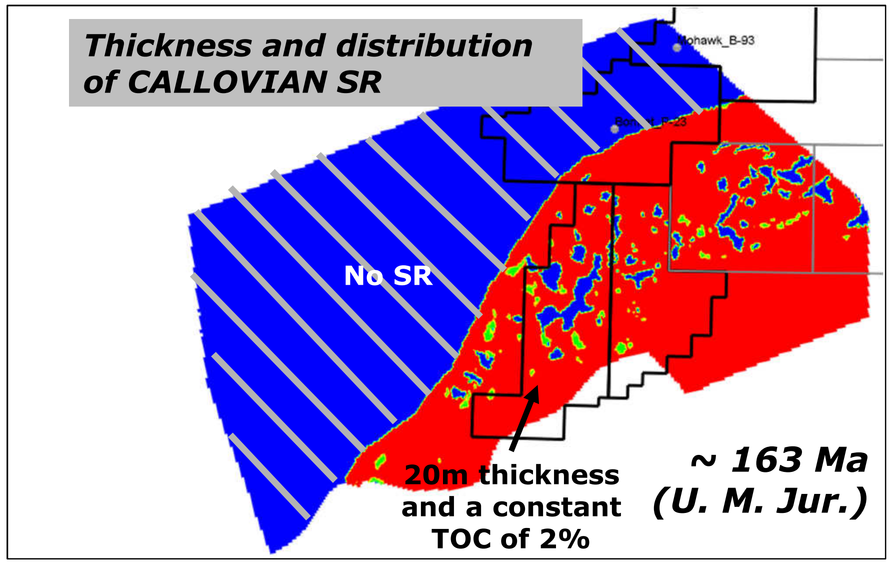
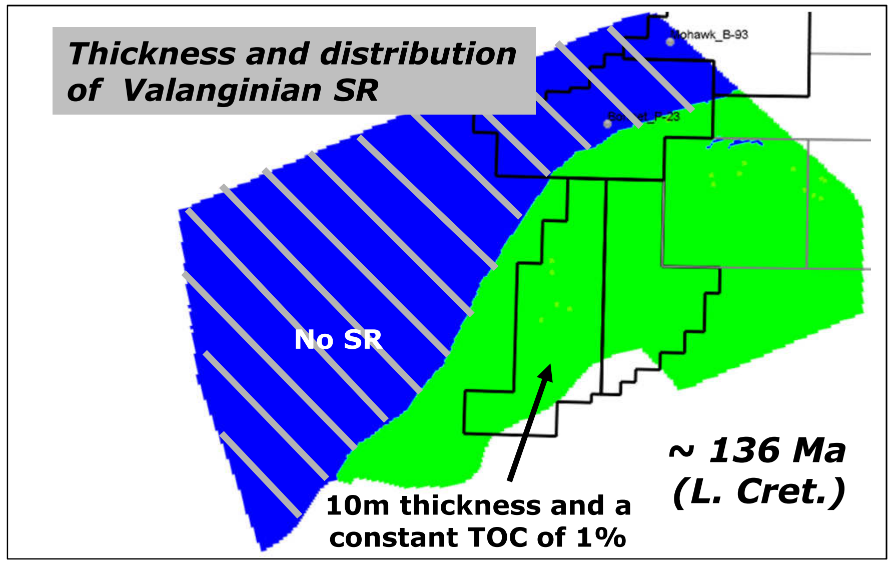


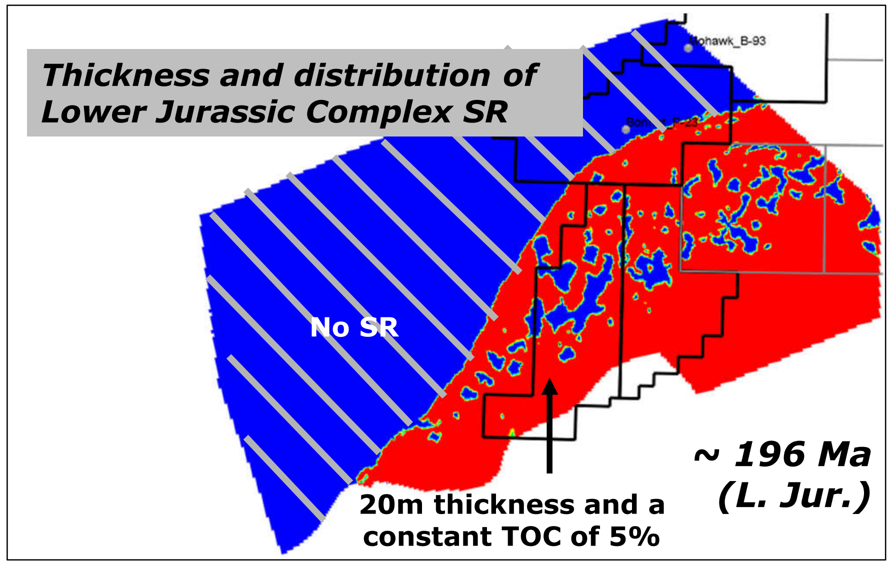
Figure 2: Salt evolution through time with diapirism and salt canopies formation.

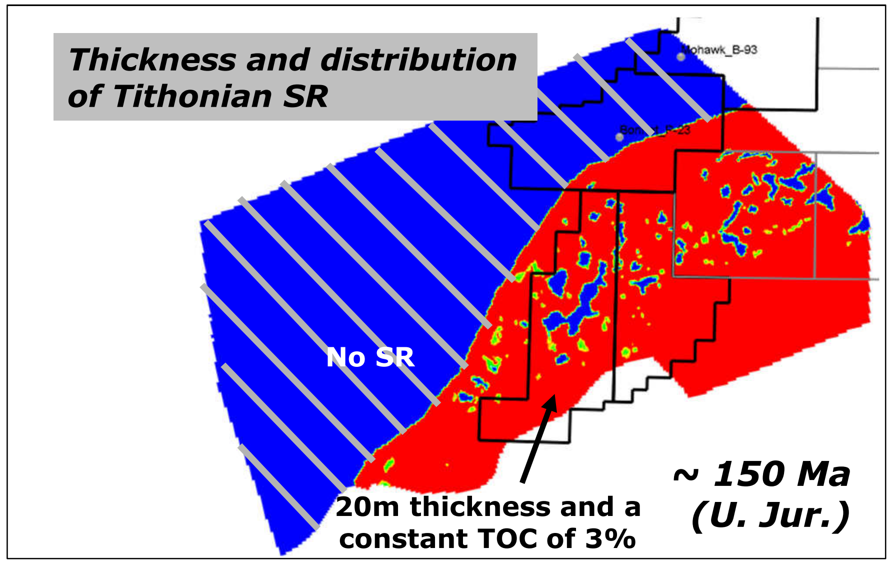












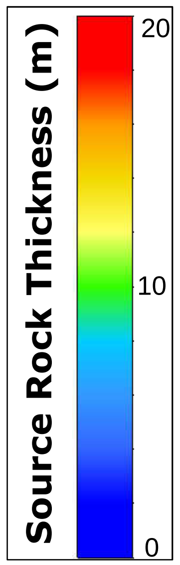


Figure 3: SR thicknesses and distribution.

For each source rock, the "Source Rock Thickness" corresponds to the cumulated thicknesses of organic-rich intervals ("effective source rock thickness"). This thickness is estimated with well geochemical data (Rock Eval data) and structural data from PFA2011. Thickness of the Lower Jurassic Complex SR is speculative (Figure 3).

Each source rock is considered as a single organic-rich layer (regarding the deposition context) with a constant thickness in the 3D model.

Source rocks petrophysical facies is defined as a specific shaly facies (to help expulsion), a carbonate detritic facies and a fault facies. Facies distribution (like the others layers) was defined from Dionisos® facies maps.

TOC is assumed as a constant value (see table below) where the deposition context allows the presence of a SR.

See the Table 2 below for more details.

Source Rock	Approx. Age	Initial TOC	Kerogen type Initial HI	Description
Aptian	124 Ma	2 % (constant)	III (continental) HI = 235 mgHC/gTOC (Dogger. North Sea) - Open system kinetics - Vandenbrouke et al. 1999	Potential source rock in the Naskapi shale (and equivalent), identified in some wells. Variable effective thickness between 0 – 10 m.
Valanginian	136 Ma	1 % (constant)	III (continental) HI = 235 mgHC/gTOC (Dogger. North Sea) - Open system kinetics - Vandenbrouke et al. 1999	Very poor and scattered source rock (coal fragments in deltaic environment, through the Mississauga formation) Variable effective thickness between 0 – 10 m.
Tithonian	150 Ma	3 % (constant)	II-III mix HI = 424 mgHC/gTOC	Best defined SR, widely proven. Variable effective thickness between 0 – 20 m.
Callovian	163 Ma	2 % (constant)	II-III mix HI = 424 mgHC/gTOC	Potential source rock in the Misaine shale (and equivalent), uncertain extend and richness due to the lack of data. Variable effective thickness between 0 – 20 m.
Lower Jurassic Complex	196 Ma	5 % (constant)	II (marine) HI = 600 mgHC/gTOC (Toarcian. France) - Open system kinetics - Behar et al. 1997	Suspected, not proven (Pleisbachian/Toarcian SR). Potentially present above salt basins only. Assumed average thickness 20 m.

Table 2: SR description with deposition age, TOC, kerogen type.

5 Source Rocks in the 3D Block.

Name	Kerogen	Molar Weight[g/mol]	Compound Type	Mobility	Default Phase	Thermal Stability
6_Coke		18.04	SOLID_OM	IMMOBILE	LIQUID	STABLE
5_C1-biogenique		16.0	HYDROCARBON	MOBILE	VAPOR	STABLE
4_GAS-Thermogenic		18.0	HYDROCARBON	MOBILE	VAPOR	STABLE
3_OIL-Condensate		120	HYDROCARBON	MOBILE	LIQUID	UNSTABLE
2_OIL-Normal		230	HYDROCARBON	MOBILE	LIQUID	UNSTABLE
1_OIL-Heavy		300	HYDROCARBON	MOBILE	LIQUID	UNSTABLE

Table 3: 6 classes scheme used in the study.

Chemical Scheme

IFP 6 classes – 5 mobile fractions (edited from IFPEN default library and from PFA 2011) used in the model (Table 3).
Maturation of initial kerogens can generate 6 families of chemical components.
Two gas families (biogenic and thermogenic), three oil families (from the heavier compounds to the lighters) and coke.
A "mobile" fraction can migrate in reservoir layers, while an "immobile" fraction is solid or very viscous and remains in the Source Rock layer.
An "unstable" chemical fraction can be altered by secondary cracking. The secondary cracking generates lighter compounds.

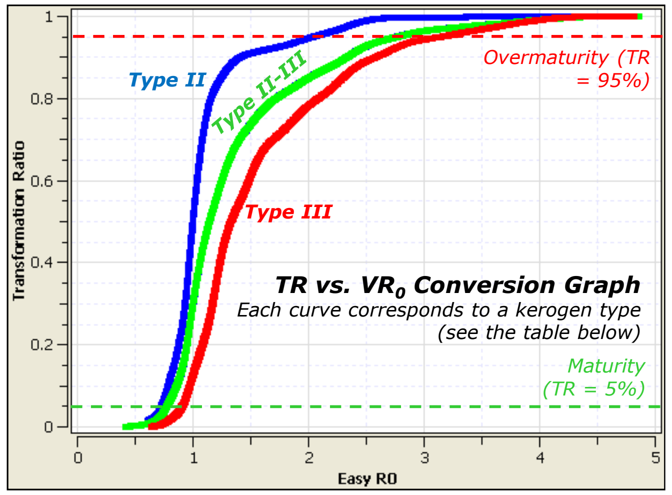
Name	Reference density[kg/m³]
5_C1-biogenique	0.6678
4_GAS-Thermogenic	50.0
3_OIL-Condensate	780
2_OIL-Normal	860
1_OIL-Heavy	980

Table 4: HC classes densities at surface conditions.

Average Densities at Surface Conditions (for the 5 mobile hydrocarbons classes)

Density are empirically defined for each fraction, and calibrated with API gravity observed in the Nova Scotia Basin (PFA 2011).

The gas densities are clearly affected by the presence of methane which is dominant in the Sable Sub Basin where calibration is possible.
Note that densities (and other parameters not presented here such as PVT parameters) are "average" values for each fraction.
These values are used for the calculation of volumes in surface conditions (0.1 MPa, 20°C).



Relationship TR/Vitrinite	TR=5% Oil Window	TR=50%	TR=95% Overmaturity
Kerogen Type II	VR$_0$ = 0.7	VR$_0$ = 0.9	VR$_0$ = 2
Kerogen Type II-III	VR$_0$ = 0.75	VR$_0$ = 1	VR$_0$ = 2.7
Kerogen Type III	VR$_0$ = 0.8	VR$_0$ = 1.2	VR$_0$ = 3.2

Graphic and Table 5: Relation between TR and vitrinite by kerogen types.

Transformation Ratio vs. Vitrinite Reflectance

The Transformation Ratio (TR) corresponds to the fraction of initial kerogen that has been affected by maturation reactions. It is expressed in percent:

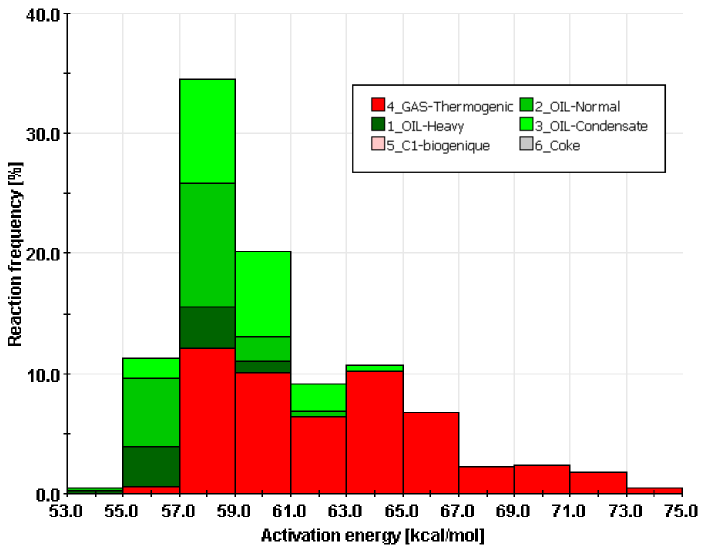
TR = observed HI / initial HI

The TR is representative of the maturity level of a given kerogen (and so of a source rock), while the vitrinite reflectance/EasyRo is an absolute maturity marker (not specific to a kerogen type).

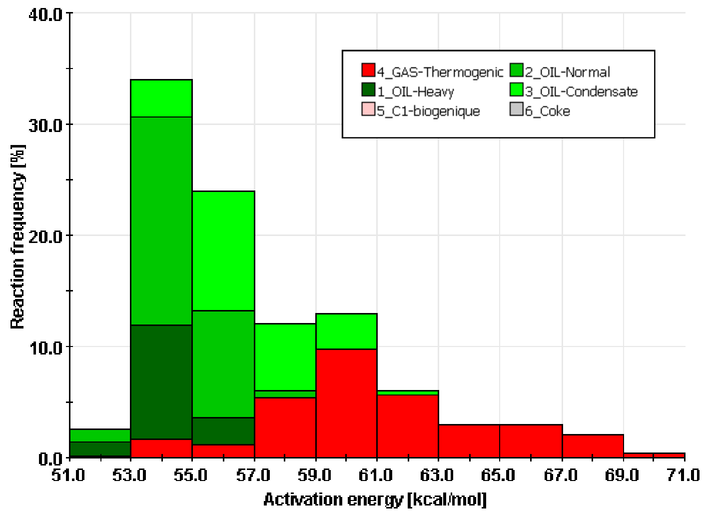
The correspondance by kerogen type is shown by Graphic and Table 5.

Type III kerogen

(Brent - Dogger. North Sea) - Vandenbrouke et al., 1999



Type II-III kerogen (mix)



Type II kerogen

(Mesnil-2 - Toarcian. France) - Behar et al. 1997

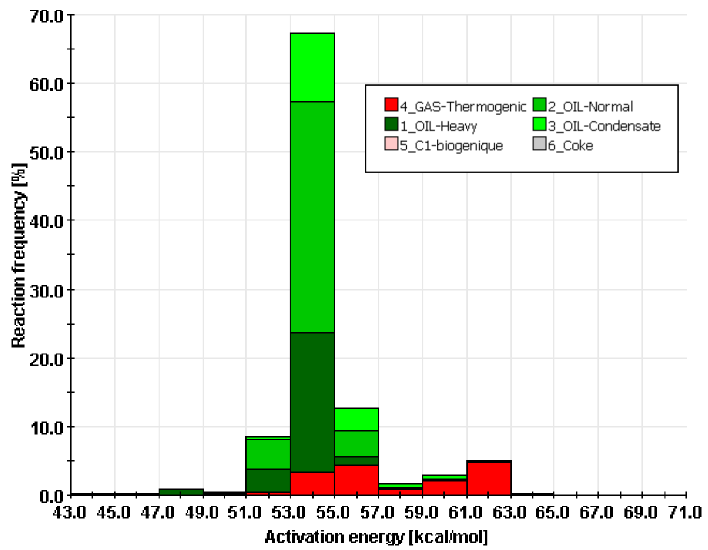


Figure 4: Different kinetic schemes used in the study.

Kinetic Scheme

Kerogen maturation follows "kinetic schemes" specific to each kerogen type.
The maturation process is divided in "n" parallel chemical reactions which have their own reaction speeds. Reaction speed is calculated with the Arrhenius Law and depends on: the Activation Energy, the Arrhenius Coefficient (specific to each chemical reaction), and the temperature. Each reaction generates chemical fractions defined by the chemical scheme.
Figure 4 details the 3 kinetic schemes used in this study (Type III, Type II-III, Type II). These schemes were edited from the IFPEN Default Library (specific data not available for Nova Scotia).
Secondary cracking reactions follow the same kind of kinetics laws.

Secondary Cracking

Following the Arrhenius Law, each unstable component can generate new chemical fraction that can be stable or unstable (and so, may generate other components by secondary cracking).
Table 6 details the 3 kinetic schemes used in this study (heavy oil, normal oil and condensate). These schemes were edited from the IFPEN Default Library (specific data not available for Nova Scotia).

Name	Activation Energy[kcal/mol]	Pre-exponential Factor[1/s]	1_OIL-Heavy[%]	2_OIL-Normal[%]	3_OIL-Condensate[%]	4_GAS-Thermogenic[%]	5_C1-biogenique[%]	6_Coke[%]
1_OIL-Heavy	48	1E10		40	15	5	0	40
2_OIL-Normal	50.5	1E10	0		55	30	0	15
3_OIL-Condensate	66.5	3.85E16	0	0		75	0	25

Table 6: Secondary cracking scheme for heavy oil, normal oil and condensates.

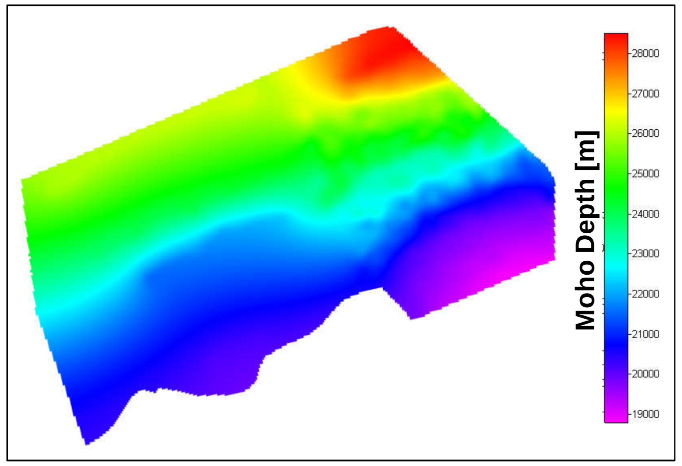


Figure 5: Moho depth.

Moho Depth

The Moho depth (Figure 5) varies between 18 and 29 km in the study area (After *Dehler and Welford 2013*).

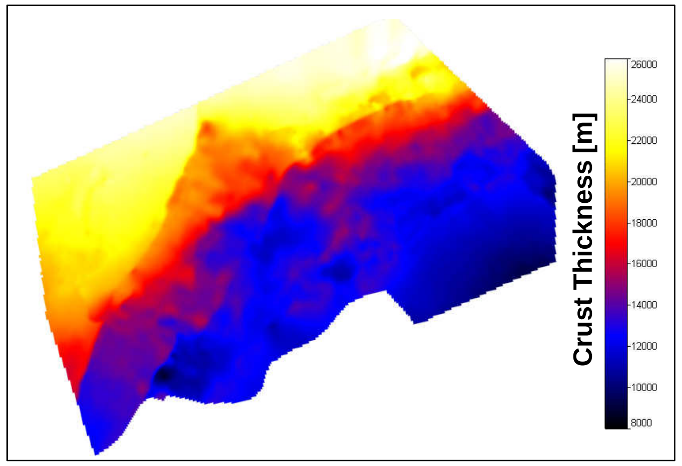


Figure 6: Crust thickness.

Crust Thickness

The thickness of the crust (Figure 6) in the model is calculated with the Moho depth map (After Dr. Sonia Dehler from the GSC) and the Top Basement depth map provided by seismic interpretation . This "top basement" corresponds to the base of the autochtonous salt: pre-salt sediments (Triassic and older) are included in the Basement.

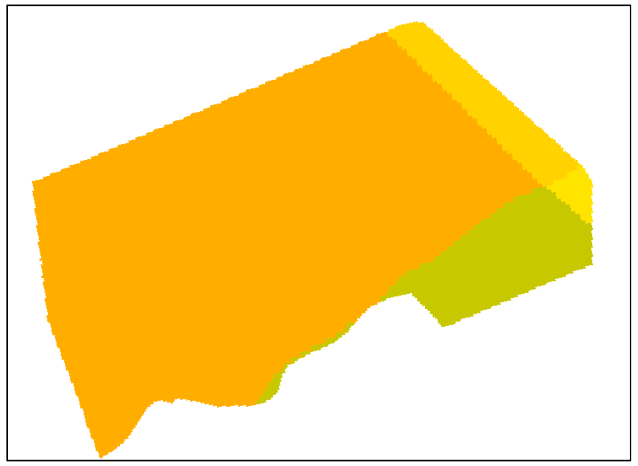


Figure 7: Upper crust lithologies distributions.

Upper Crust Lithology

		Average Crust Radiogeny
	upper_continental_crust_2	+
	upper_continental_crust_4	
	upper_continental_crust_5	
	transition_crust	
	oceanic_crust	-

The Upper Crust lithology has a strong influence on the thermal modeling: the continental crust is usually rich in radiogenic elements, while the oceanic crust does not generate radiogenic heat. Different types of continental crust with different content in radiogenic elements are considered.

The repartition of crustal lithologies (Figure 7) is estimated with geophysical data (estimated rock densities, seaward dipping reflectors) and thermal calibration with well data (from this study and PFA 2011).

Other Basement Parameters

Initial Crust Thickness Before Rifting (Upper + Lower Crust)	**42 km** (cte)
Upper Crust / Total Crust (ratio in %)	**60%** (continental domain) **30%** (oceanic domain)
Initial Lithosphere Thickness Before Rifting (crust + lithospheric mantle)	**120 km** (cte)
Bottom Temperature (lithosphere / asthenosphere boundary)	**1330 °C** (cte)

Table 7: Basement parameters used in the study.

Basement Structure

Basement structure has a strong impact on thermal modeling due to:
- The rifting at the beginning of the modeling (about 220 to 196 Ma);
- The disintegration of radiogenic elements in the crust;
- The better constraint on the "Blancketing Effect" due to high sedimentation rates.

Table 7 shows the parameters used in this study.

Rifting History at 3 key ages (Figure 8)

Before Rifting (220 Ma)

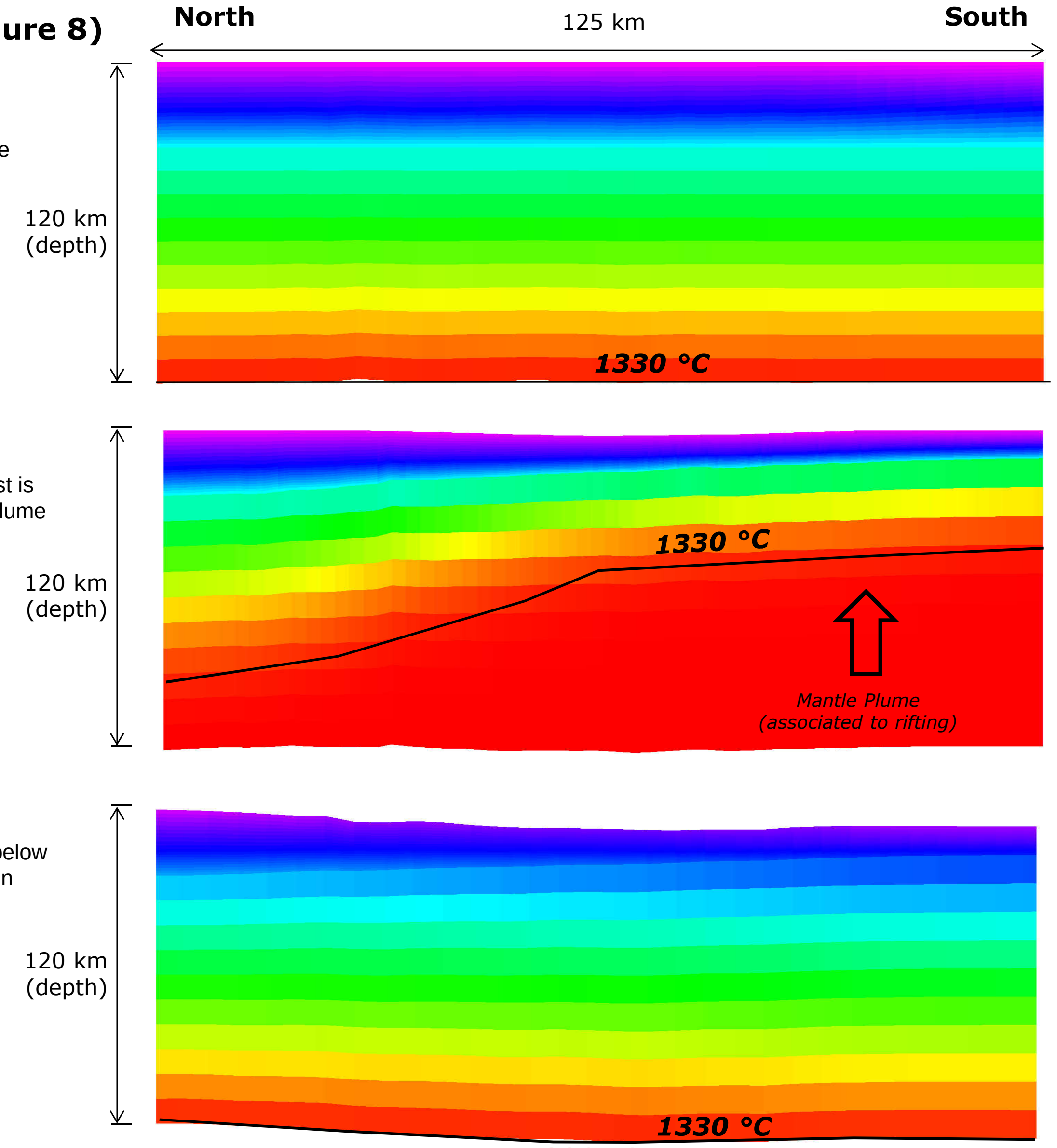
Relatively uniform temperature field.
1330°C at the base of the lithosphere (base of the model).

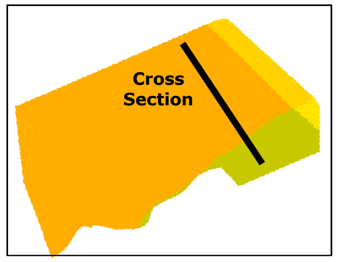
After Rifting (197 Ma)

Heating due to the rifting. The thinning of the crust is stronger seaward (ocean opening). The mantle plume is also bigger southward.

Present Day (0 Ma)

Slow cooling after the rifting. At the same depth below the surface, temperature is lower seaward than on the shelf at present day.





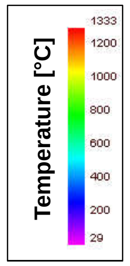


Figure 8: Rifting and temperature evolution through time.

SURFACE TEMPERATURE THROUGH TIME

Surface temperature has a significant impact on thermal modeling. Sea bottom temperature evolution through time is required. Paleotemperatures are estimated in function with the paleobathymetry and paleoclimates/paleoenvironments (Figure 9).

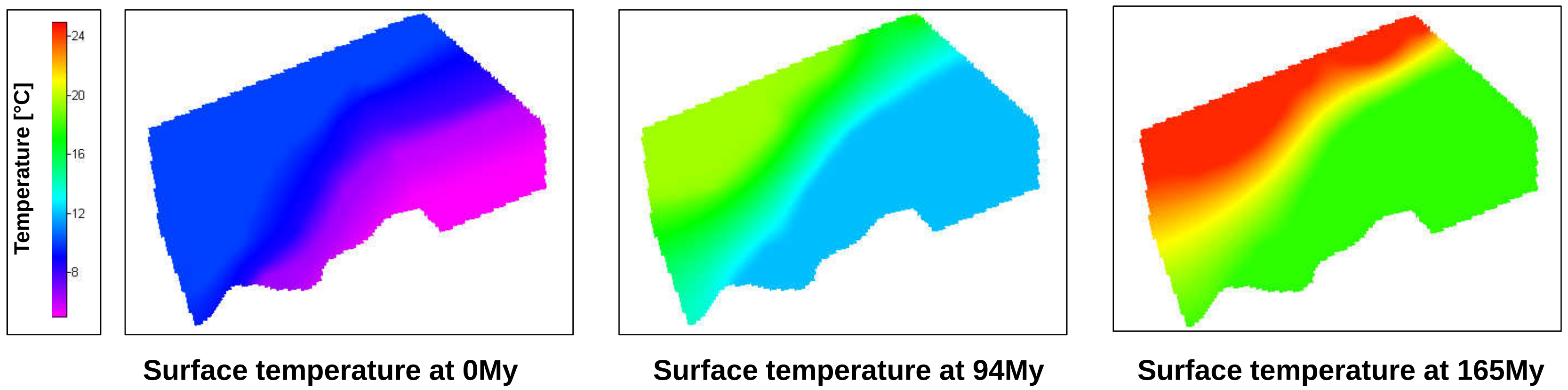


Figure 9: Surface temperature evolution through time.

CHAPTER 7.2

BASIN MODELING – MATURATION/EXPULSION SIMULATION

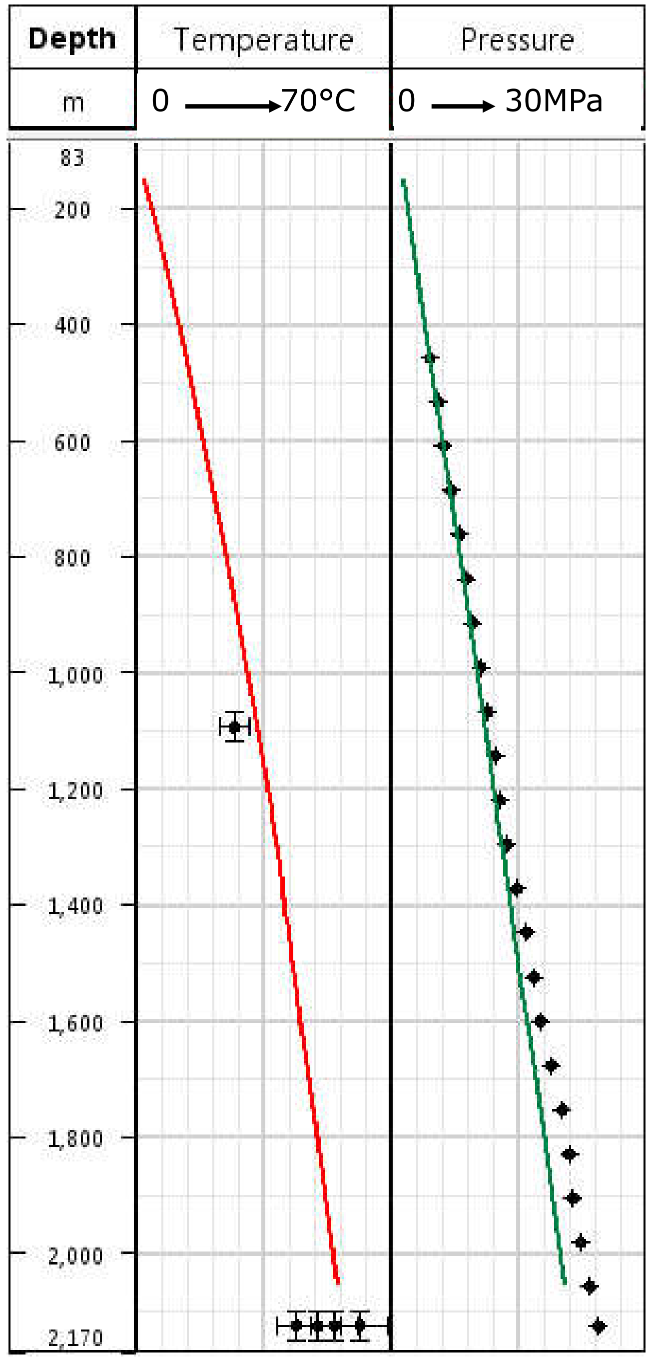
The **1st modeling stage** consists in the temperature, pressure, maturity, and expulsion modeling, with the basin modeling software Temis Flow 3D®.

The evolution of the whole 3D block (geological model) is simulated through geological times:

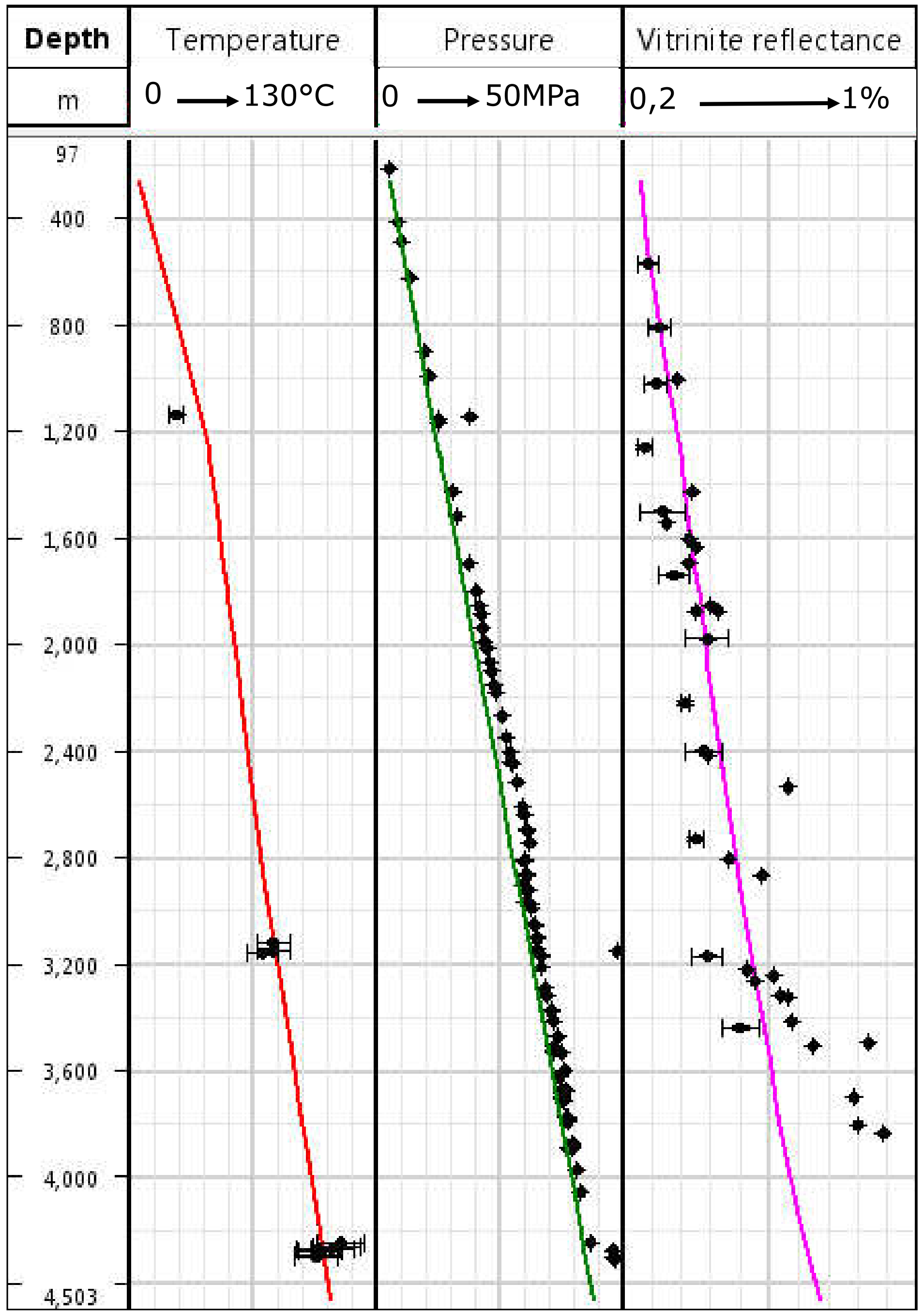
→ Modeling of progressive burial due to sedimentation
→ Sediment compaction with the "back stripping method"
→ Structural evolution (uplift, subsidence, normal faults activity, etc.)
→ Water flow modeling
→ Rifting of the lithosphere (thermal effect on the sedimentary basin)
→ Computation of temperature and pressure through time in the whole 3D block
→ Computation of SR maturity through time
→ Computation of HC expulsion through time (primary migration)

Results will be used for the migration modeling and analysis (maturity, porosity, etc…).

Mohawk



Bonnet



Figures 11 and 12: Observed and simulated data on Mohawk and Bonnet. The two wells are calibrated, except deep values of vitrinite on Bonnet.

Calibrations

The 3D model is calibrated in pressure / temperature / maturity (vitrinite reflectance) with available well data (Mohawk and Bonnet, see Figure 10 for location).
The simulation results from PFA 2011 were used to keep a coherency between the two models (as a part of the 2011 model cross our model) and help to balance the lack of data.

Temperature and pressure from the simulation fits with the observed data (Figures 11 and 12).

On Bonnet (Figure 12), vitrinite fits until 3200m where we can see an anomalous increase. This anomaly is not taken into account for calibration (we explore an hypothesis that calibrate this well in a separate part (hot spot during Cretaceous) – see Chapter 7.4.

Location of the 2 wells (Mohawk and Bonnet) used for calibration

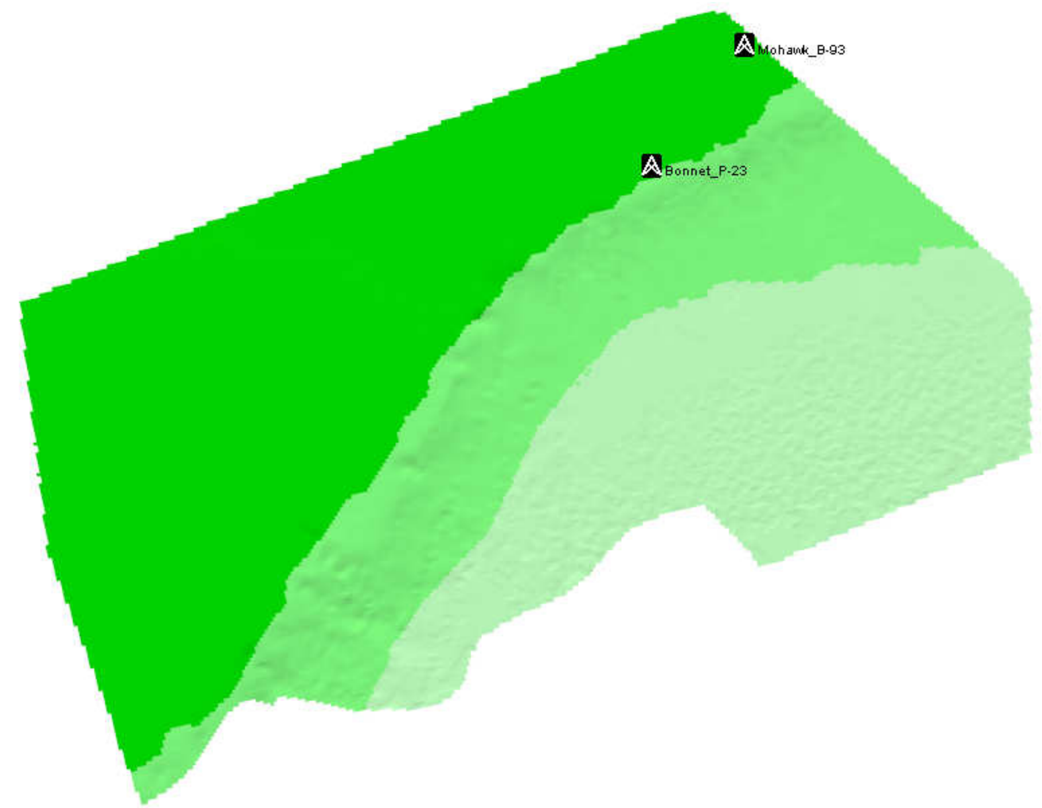
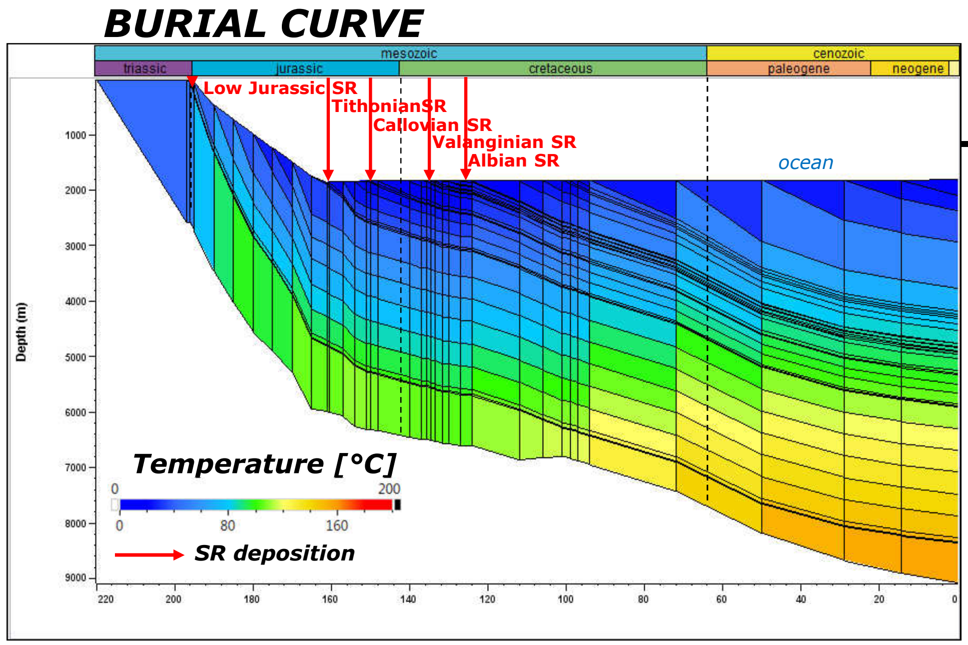
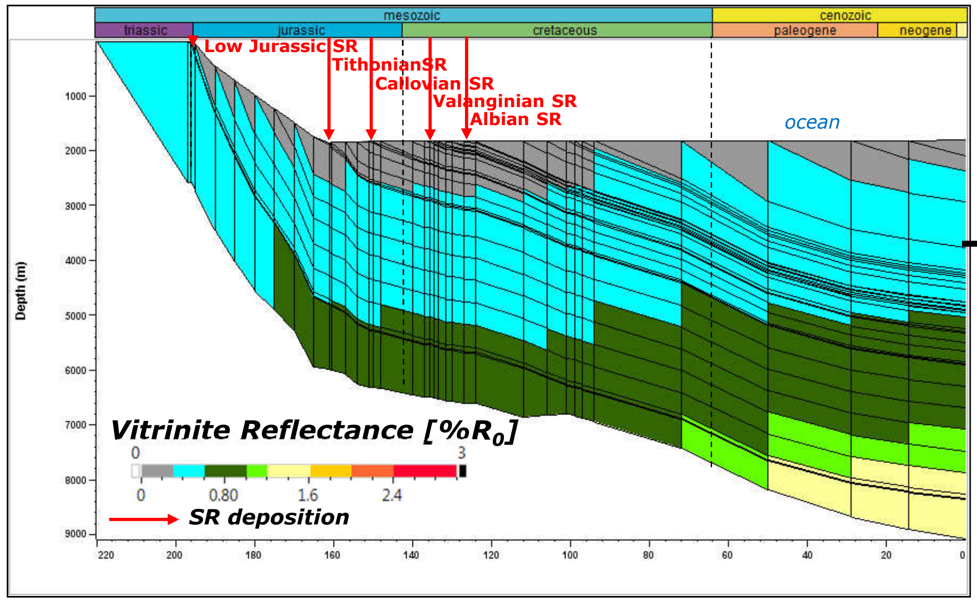
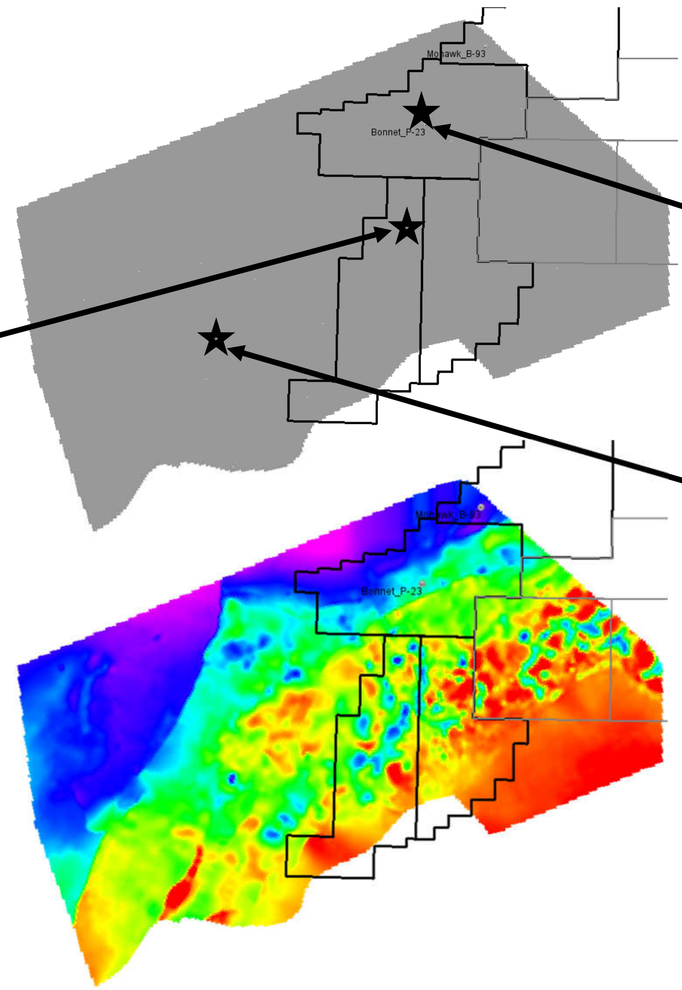


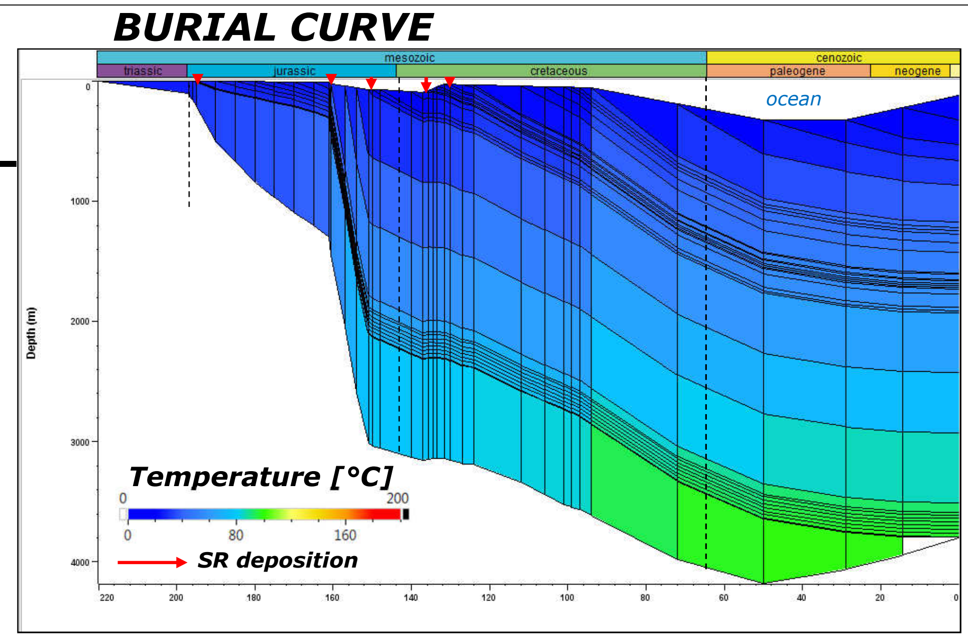
Figure 10: Mohawk and Bonnet location on the model.

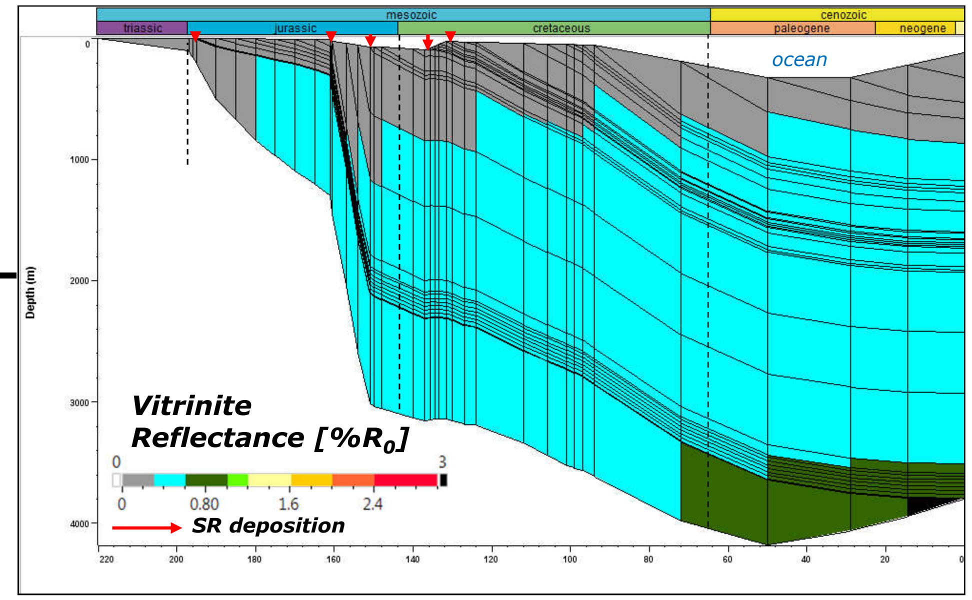


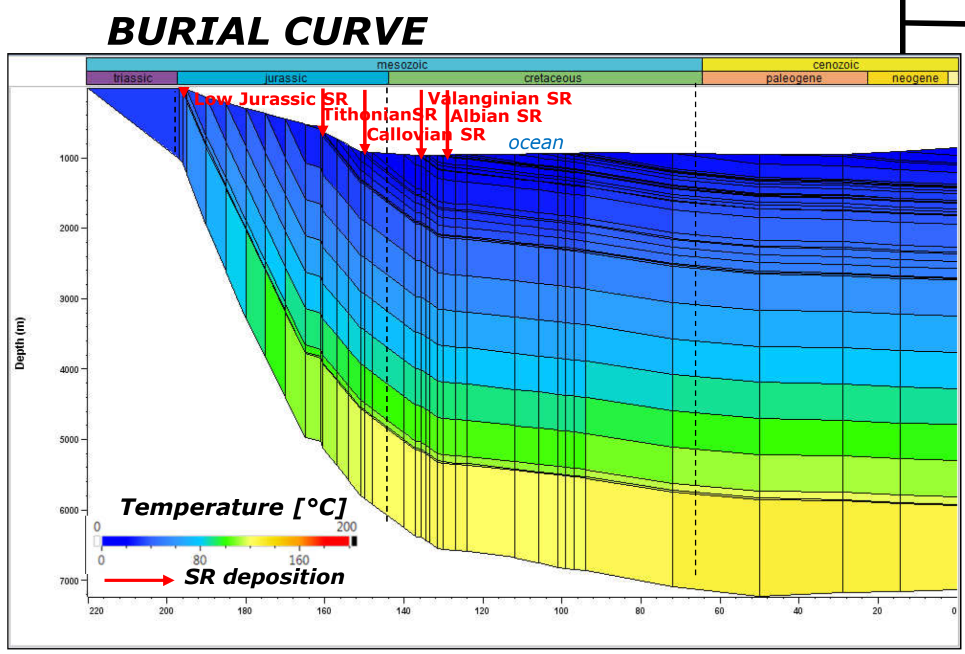




Burial Curves gives the evolution of the burial through time, at a precise location in the Basin. Temperature, vitrinite, and overpressure evolution are indicated through time. Parameters are calculated at the cell center.







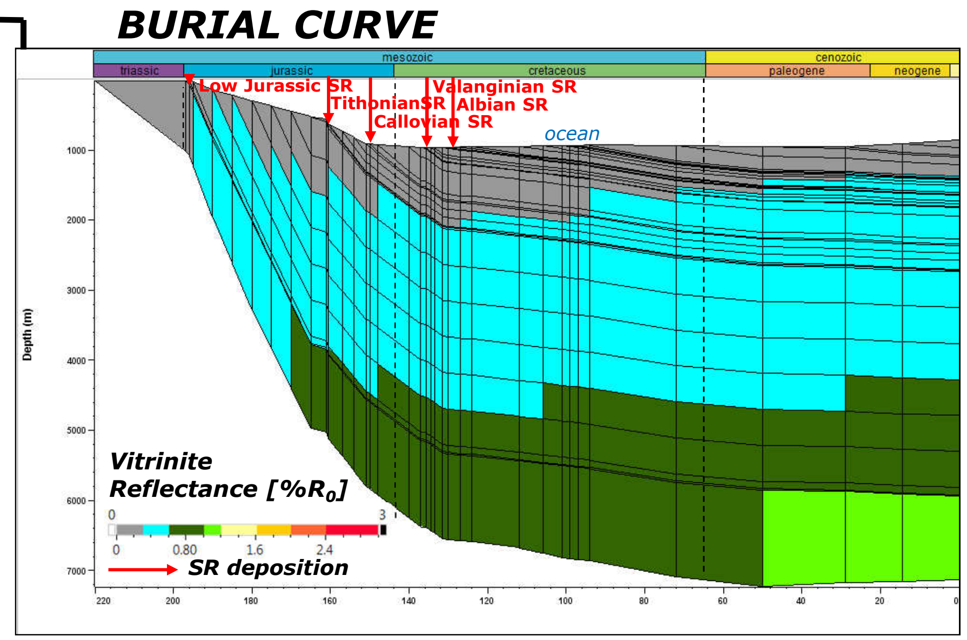


Figure 13: Simulated temperature and vitrinite in some key areas of the basin.

Temperature

Temperature (Figure 13) are relatively low in that basin. The temperature reaches 180°C -190°C in deepest part of the basin (due to salt movement, see depth map). At this temperature and with this history, we can expect mostly oil. Secondary cracking will be also limited.

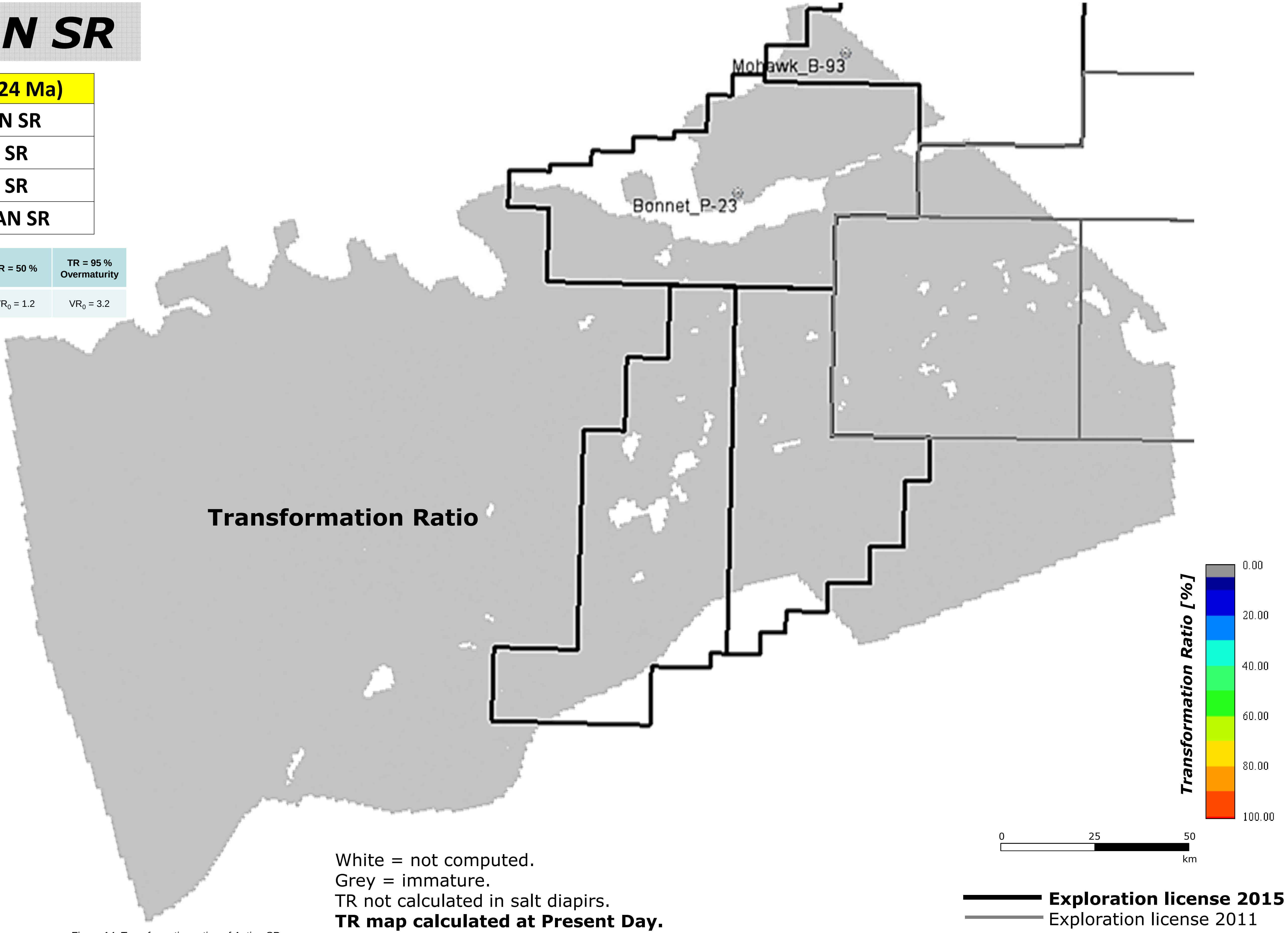
Vitrinite

Vitrinite (Figure 13) shows that the Low Jurassic SR is mature in the basin and reaches the oil window (> 1%) near end Cretaceous (90-70My) or Paleogene, depending on depth. Callovian and Tithonian SRs are at the beginning of oil window (0.6%) and reach it at Paleogene or later. Valaginian and Albian SRs are not mature.
Gas window is reach only in deepest parts of the basin and only on Low Jurassic SR.

APTIAN SR

APTIAN SR (≈ 124 Ma)
VALANGINIAN SR
TITHONIAN SR
CALLOVIAN SR
PLIENSBACHIAN SR

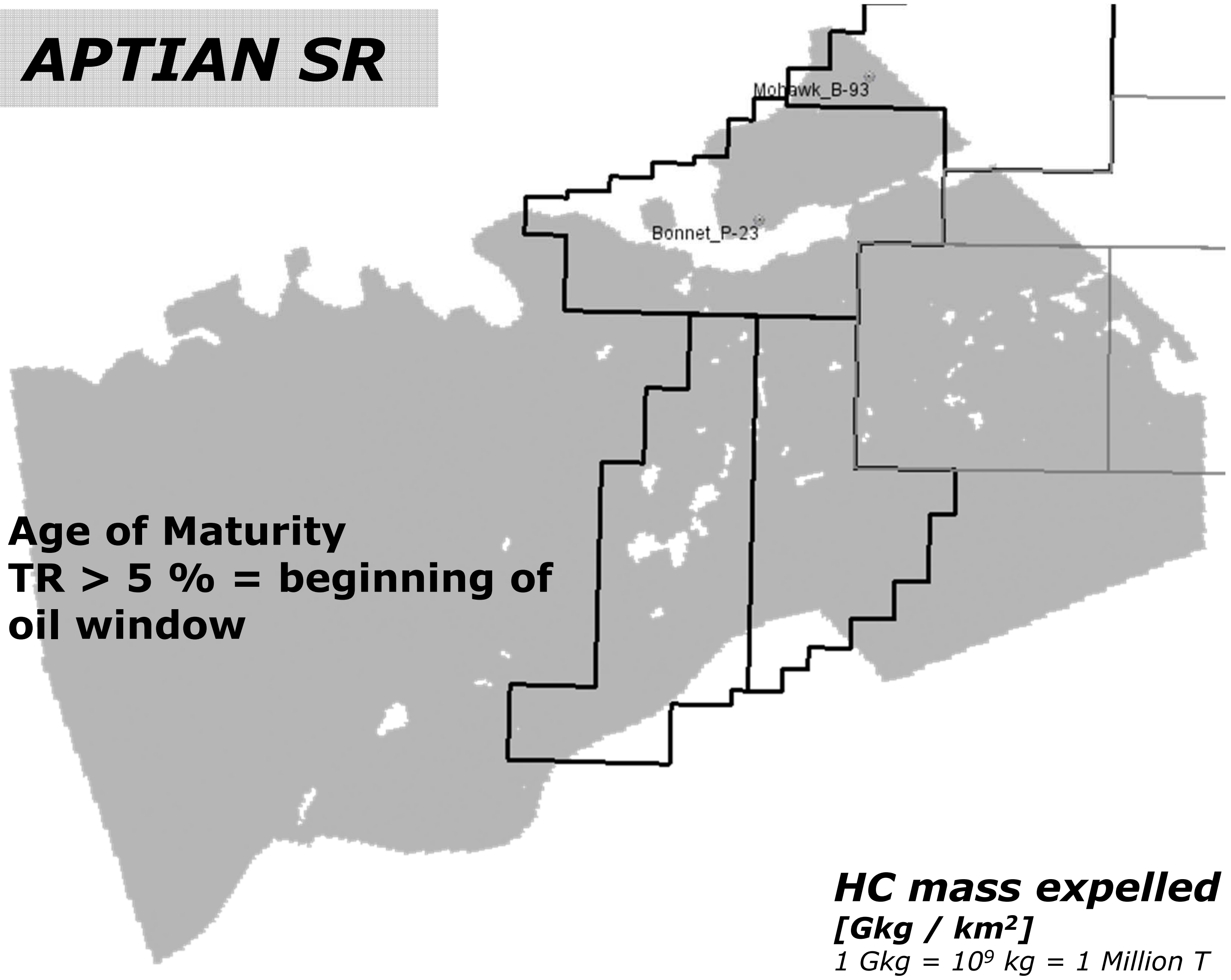
Relationship TR / Vitrinite	TR = 5% Maturity (oil window)	TR = 50 %	TR = 95 % Overmaturity
Kerogen Type III	$VR_0 = 0.8$	$VR_0 = 1.2$	$VR_0 = 3.2$

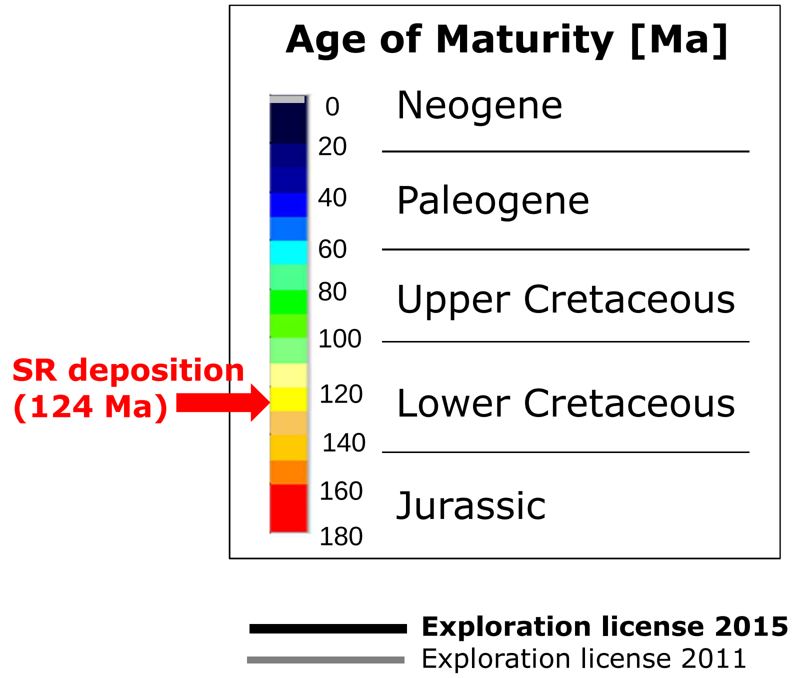


White = not computed.
Grey = immature.
TR not calculated in salt diapirs.
TR map calculated at Present Day.

Figure 14: Transformation ration of Aptian SR.

APTIAN SR





Age of maturity (in Million Years)

The map indicates the age at which the source rock reached a given level of maturity: 5% of Transformation Ratio for the beginning of maturity (oil window).

Aptian SR doesn't reach a transformation ratio of 5% (Figure 15), it is not mature.

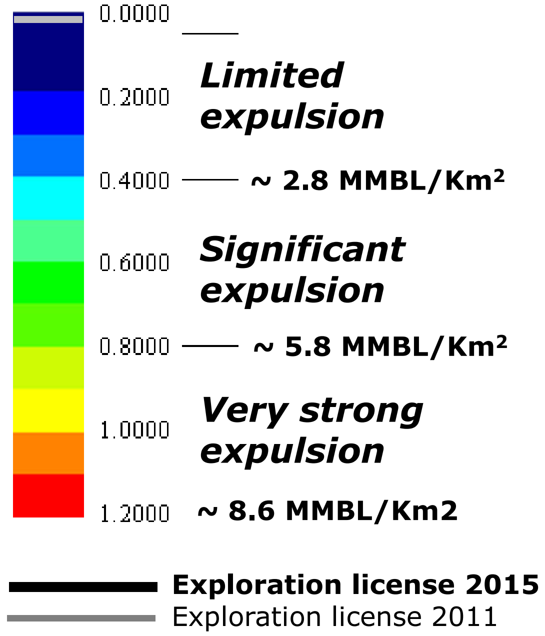
Figure 15: Ages when the Aptian SR reaches the oil window (TR >5%).

Expulsion Map at Present Day

The map gives HC mass expelled through time (cumulated mass).
HC mass expelled = oil mass expelled + gas mass expelled
Expulsion process corresponds to primary migration of HC out of SR layers. Expelled volumes are smaller than generated volumes and depend on petrophysical properties of source rocks (porosity, relatives permeability between hydrocarbons and water, irreducible water saturation, capillary pressure, etc.). Locally, the source rock can be slightly mature without expulsion.
In that study case, it is unlikely that zones with expulsion lower than 400 Gkg / km2 significantly contribute to an active petroleum system.
To convert HC mass (Gkg) in equivalent barrels of oil , multiply values by about 7,2 (average oil density estimated at 810 kg/m3).

As the Aptian SR is not mature, the amount of HC produced and expelled is negligible (Figure 16).

HC mass expelled
[Gkg / km²]
1 Gkg = 10^9 kg = 1 Million T
~ 7.2 Mbbl



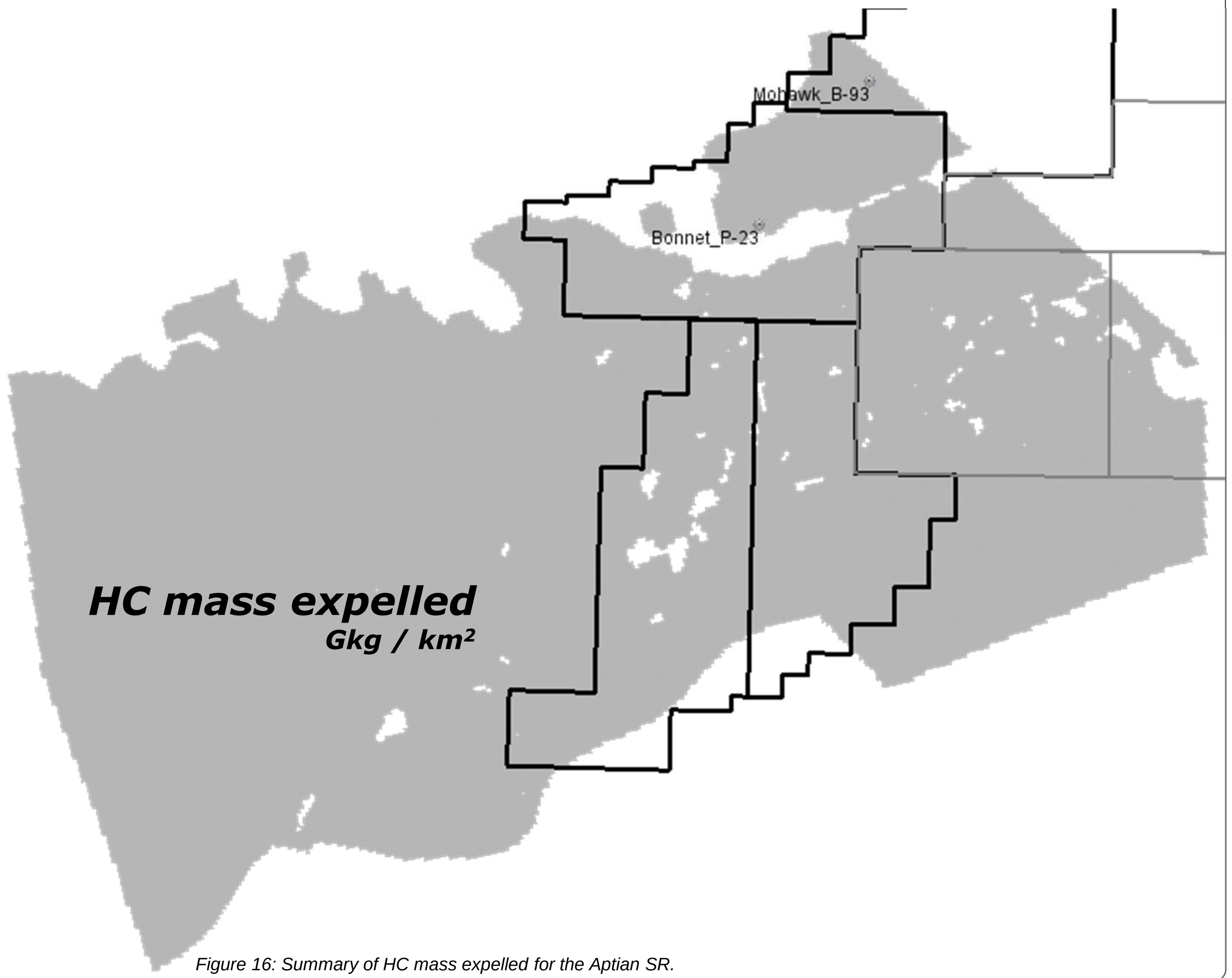


Figure 16: Summary of HC mass expelled for the Aptian SR.

VALANGINIAN SR

APTIAN SR
VALANGINIAN SR (≈ 136 Ma)
TITHONIAN SR
CALLOVIAN SR
PLIENSBACHIAN SR

Relationship TR / Vitrinite	TR = 5% Maturity (oil window)	TR = 50 %	TR = 95 % Overmaturity
Kerogen Type II	VR_0 = 0.7	VR_0 = 0.9	VR_0 = 2

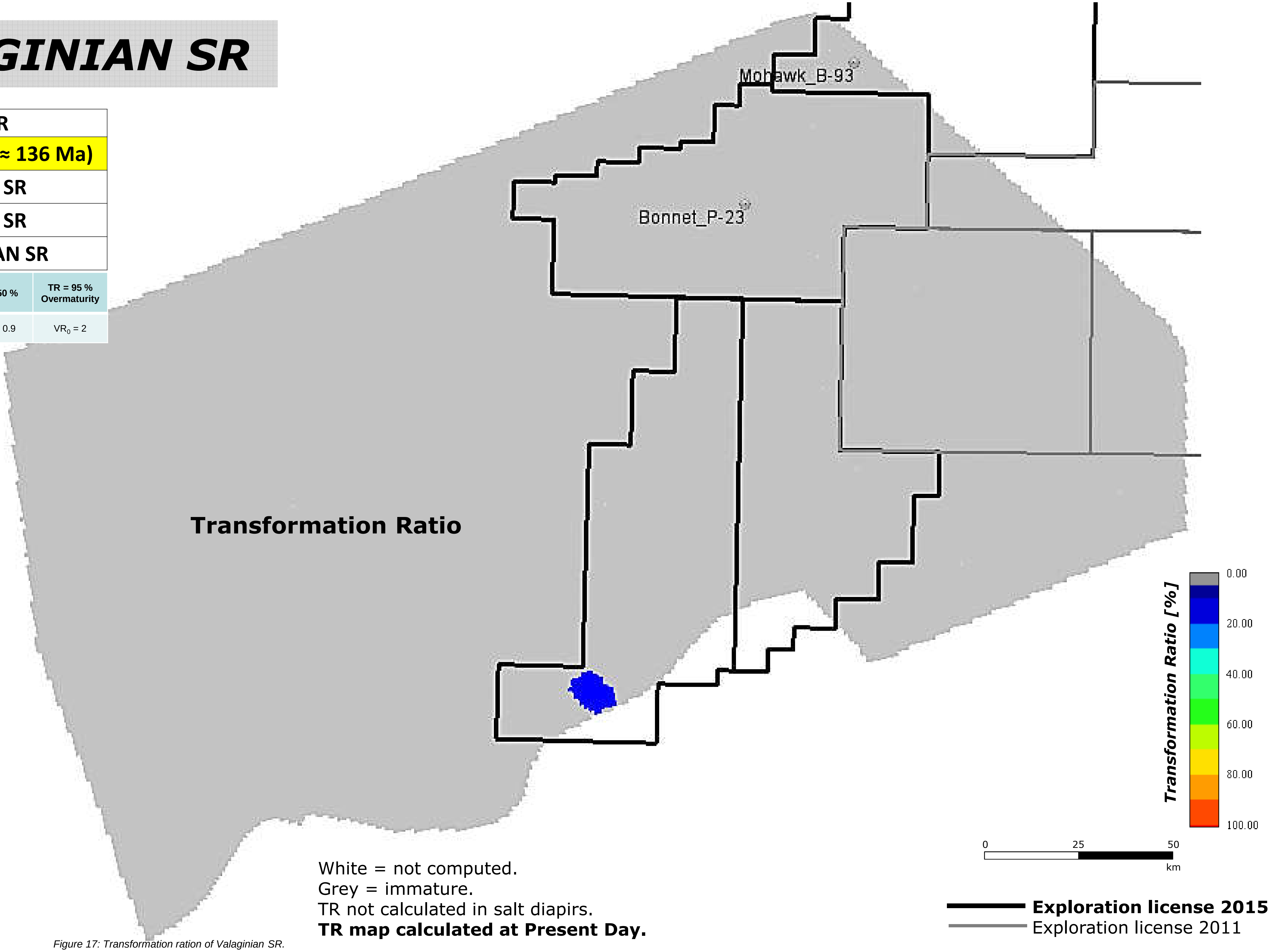


Figure 17: Transformation ration of Valaginian SR.

VALANGINIAN SR

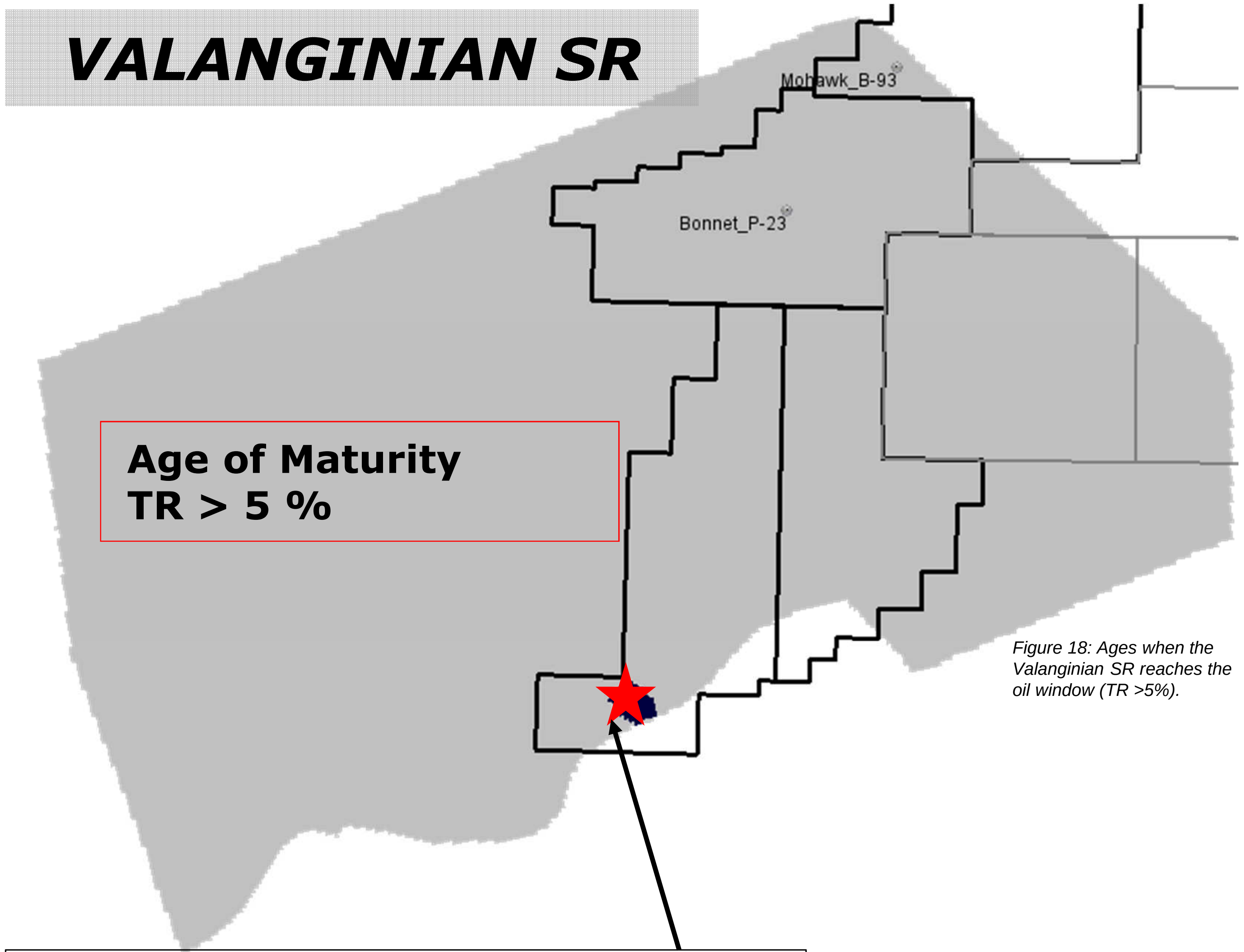
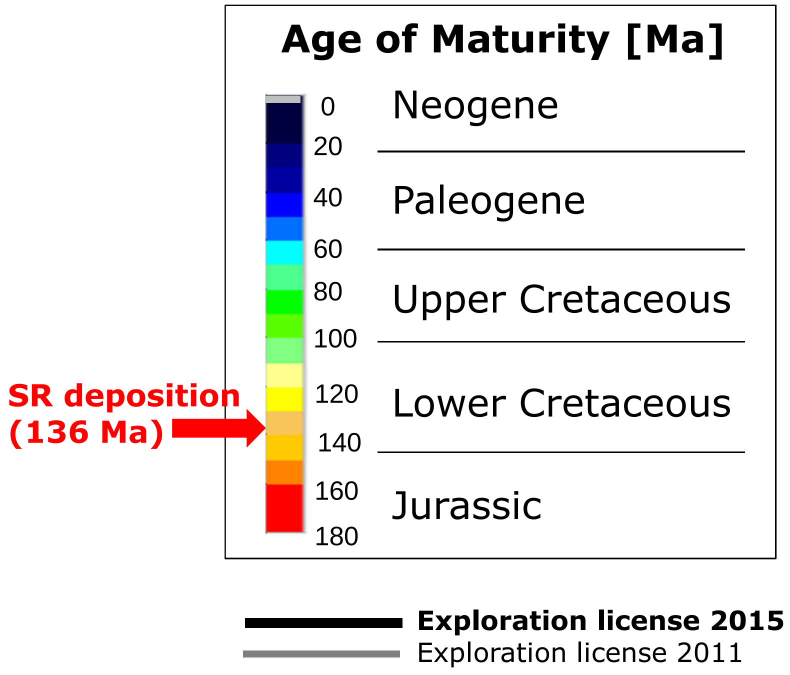


Figure 18: Ages when the Valanginian SR reaches the oil window (TR >5%).



Age of maturity and of over-maturity (in Million Years)

The map indicates the age at which the source rock reached a given level of maturity: 5% of Transformation Ratio for the beginning of maturity.

Maturation of the Valanginian SR (Figure 18) started near 8Ma on a reduced area and is not mature (doesn't reach a transformation ration of 5%) on approximatively the whole area.

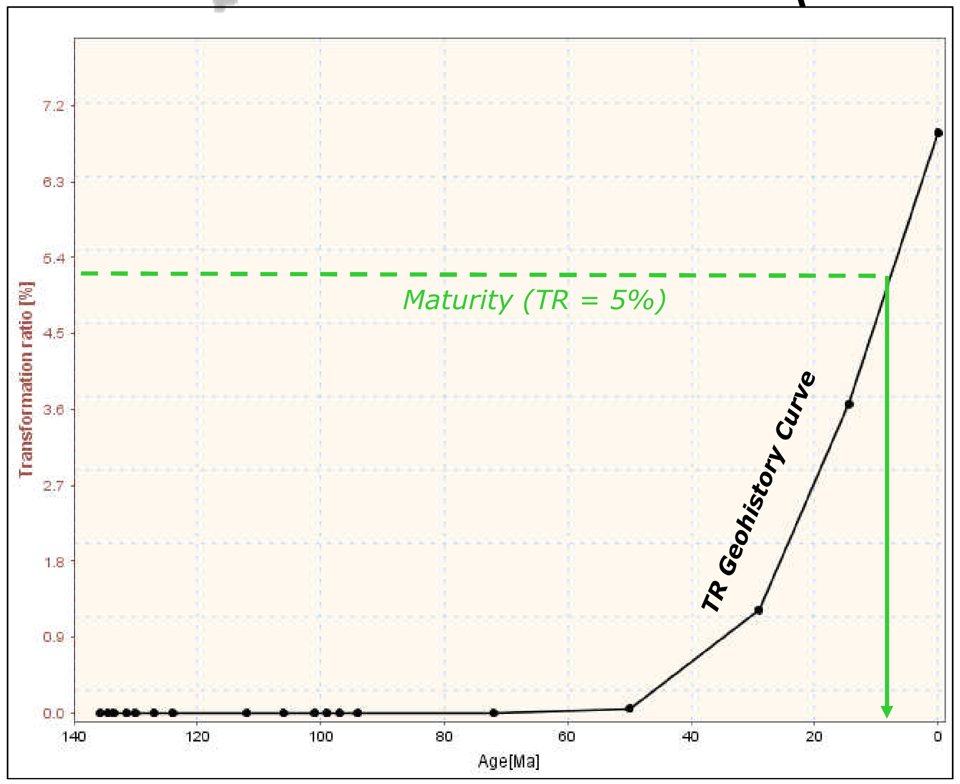


Figure 19: TR evolution through time of the Valanginian SR.

Evolution of the Maturity

The graph indicates the evolution of the Transformation Ratio through time in the area where Valanginian SR reach 5% of transformation ratio (Figures 18 and 19).

The important burial episode beginning near 70Ma is observable on this TR vs Age curve, with an augmentation of the TR at this period.

Vitrinite at Present Day

The vitrinite map is computed from the EasyRo in %.

The vitrinite, as the TR maps show us an immature SR which haves vitrinite values of 0.6-0.8 (Figure 20).

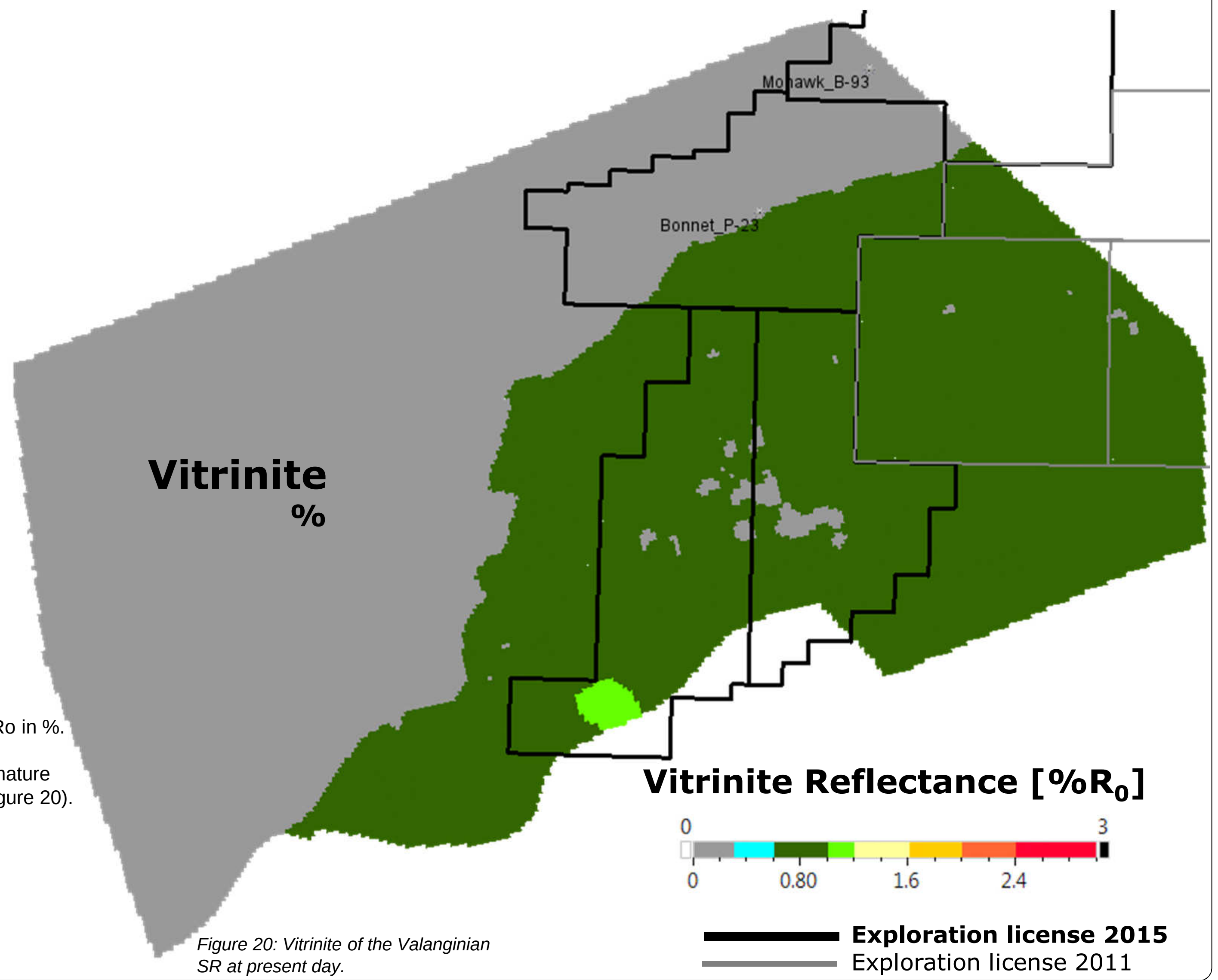


Figure 20: Vitrinite of the Valanginian SR at present day.

VALANGINIAN SR

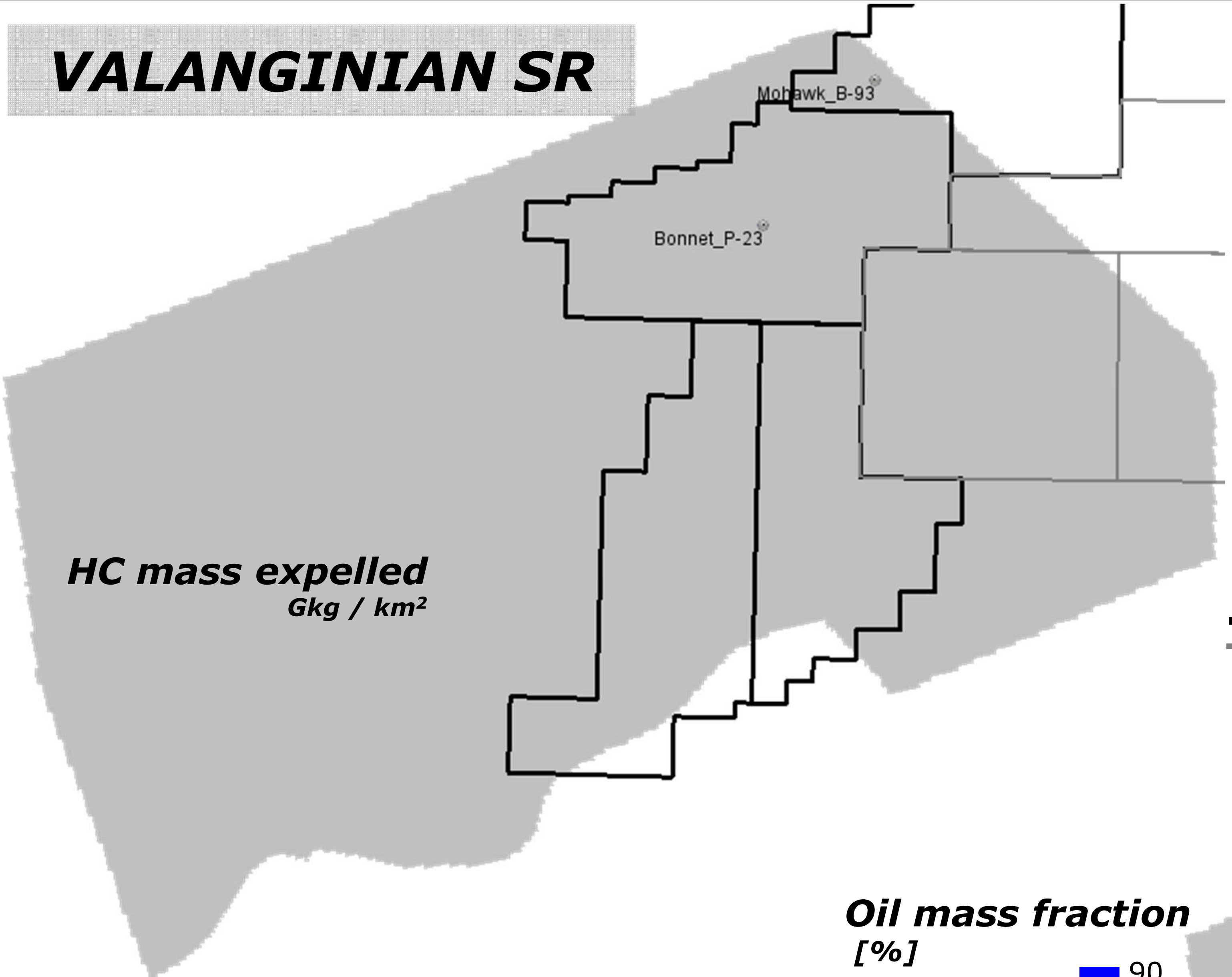


Figure 20: Summary of HC mass expelled for the Valanginian SR.

HC mass expelled
[Gkg / km²]
1 Gkg = 10^9 kg = 1 Million T
~ 7.2 Mbbl

0.0000	
0.2000	Limited expulsion
0.4000	~ 2.8 MMBL/Km²
0.6000	Significant expulsion
0.8000	~ 5.8 MMBL/Km²
1.0000	Very strong expulsion
1.2000	~ 8.6 MMBL/Km2

Exploration license 2015
Exploration license 2011

Expulsion Map at Present Day

The map gives HC mass expelled through time (cumulated mass).
HC mass expelled = oil mass expelled + gas mass expelled
Expulsion process corresponds to primary migration of HC out of SR layers.
Expelled volumes are smaller than generated volumes and depend on petrophysical properties of source rocks (porosity, relatives permeability between hydrocarbons and water, irreducible water saturation, capillary pressure, etc.).
Locally, the source rock can be slightly mature without expulsion.
In that study case, it is unlikely that zones with expulsion lower than 400 Gkg / km2 significantly contribute to an active petroleum system.
To convert HC mass (Gkg) in equivalent barrels of oil , multiply values by about 7,2 (average oil density estimated at 810 kg/m3).

For the Valanginian SR, expulsion is near 0 Gkg/km² (Figure 20) and its participation to the petroleum system can be ignored.

Oil mass fraction
[%]

90
91
92
93
94
95

OIL /TOTAL HC Ratio Map at Present Day (in percent)

The map gives the fraction of oil expelled by the source rock through time:
ratio = mass of expelled oil / total mass of expelled HC.
This ratio doesn't take into account secondary cracking of heavy HC occurring within the source rock layer as we consider that it occurs during migration (secondary cracking in the SR can be neglected due to the temperature and the amount of quantities affected).

As the Valanginian SR haves an expulsion nearly equal to 0 (Figure 21), the Oil mass fraction is equal to 0 except in a limited area where it reaches 90% (ratio of 90% oil and 10% gas).

Exploration license 2015
Exploration license 2011

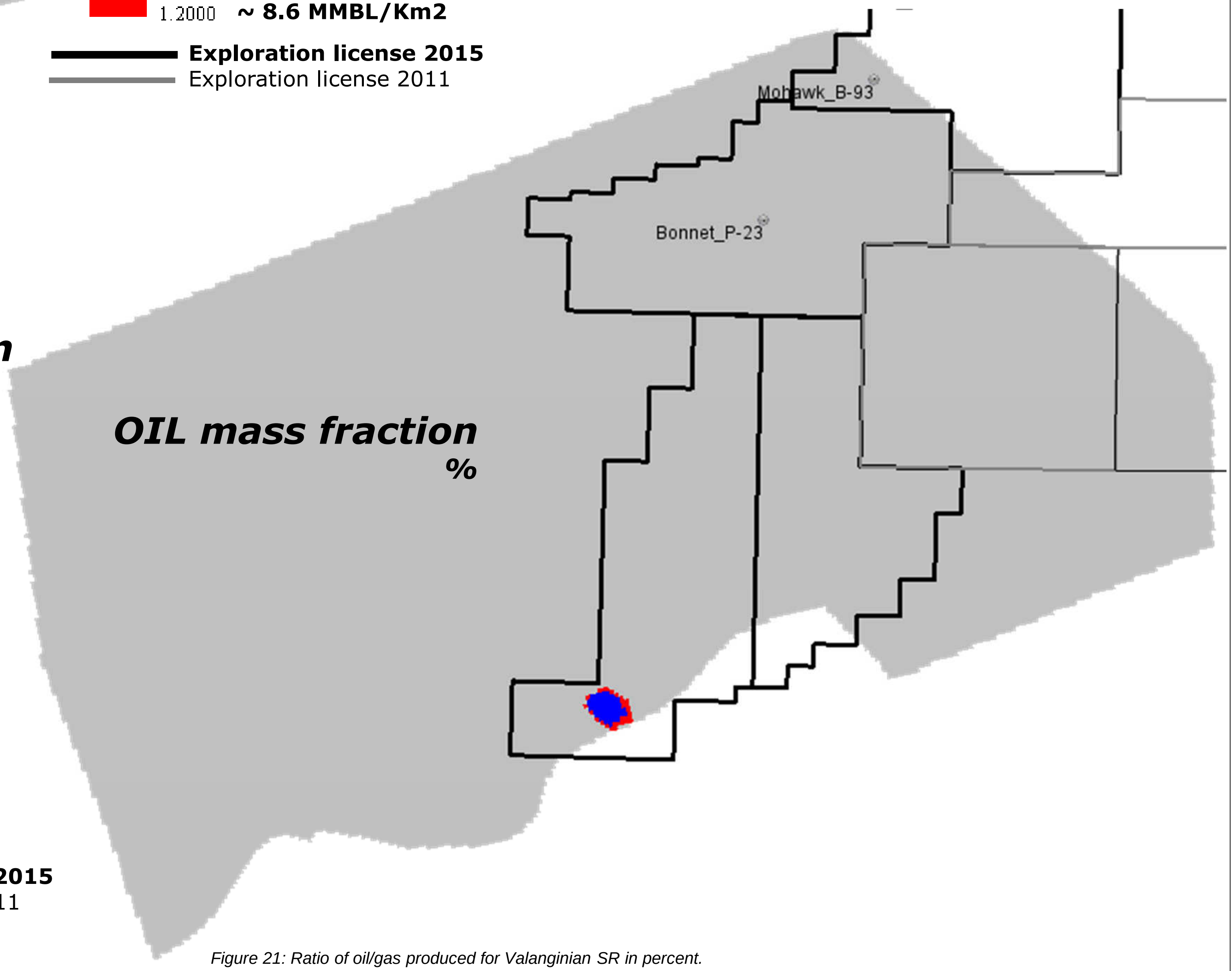


Figure 21: Ratio of oil/gas produced for Valanginian SR in percent.

TITHONIAN SR

APTIAN SR
VALANGINIAN SR
TITHONIAN SR (≈ 150 Ma)
CALLOVIAN SR
PLIENSBACHIAN SR

Relationship TR / Vitrinite	TR = 5% Maturity (oil window)	TR = 50 %	TR = 95 % Overmaturity
Kerogen Type II	VR_0 = 0.7	VR_0 = 0.9	VR_0 = 2

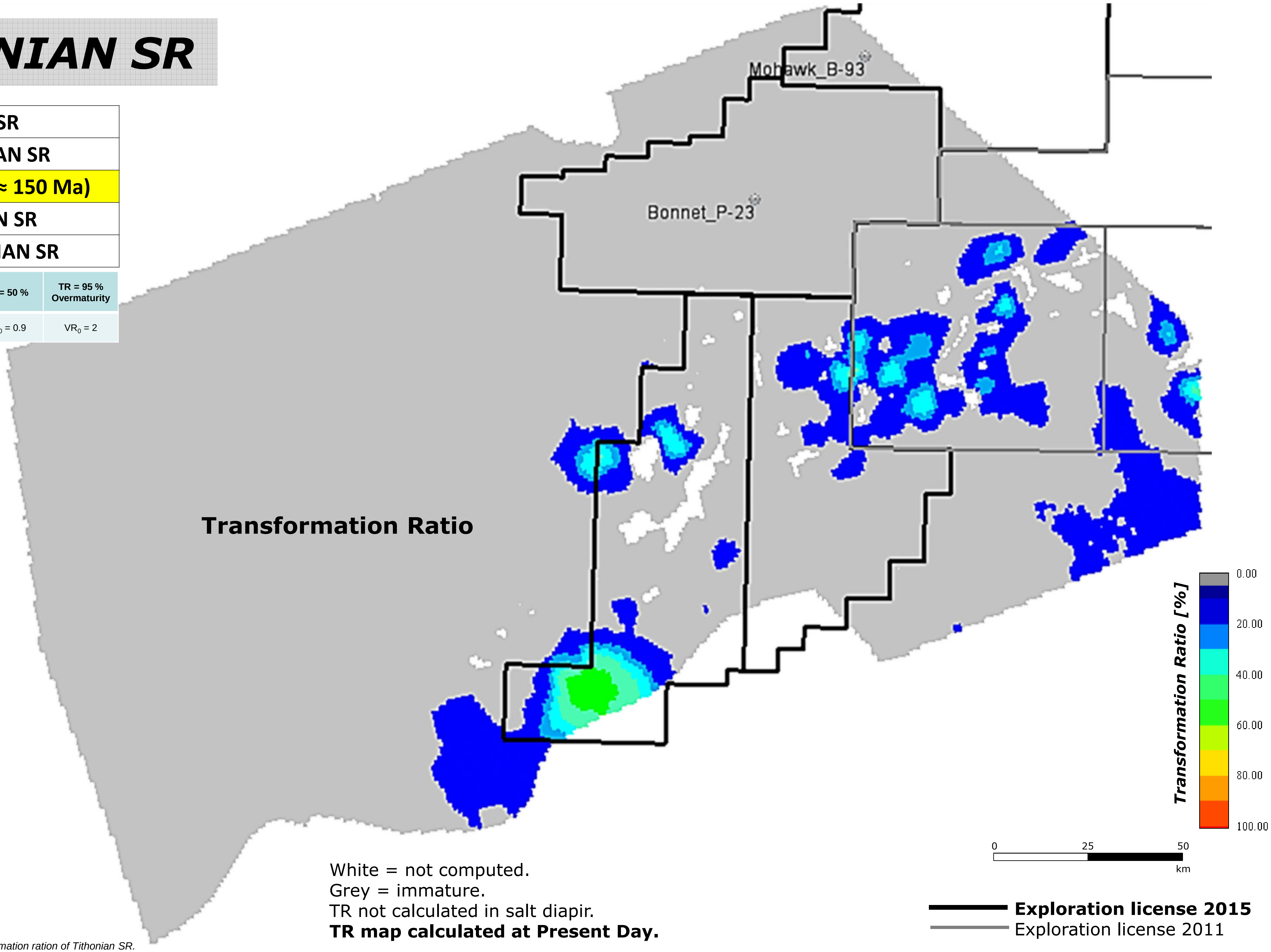
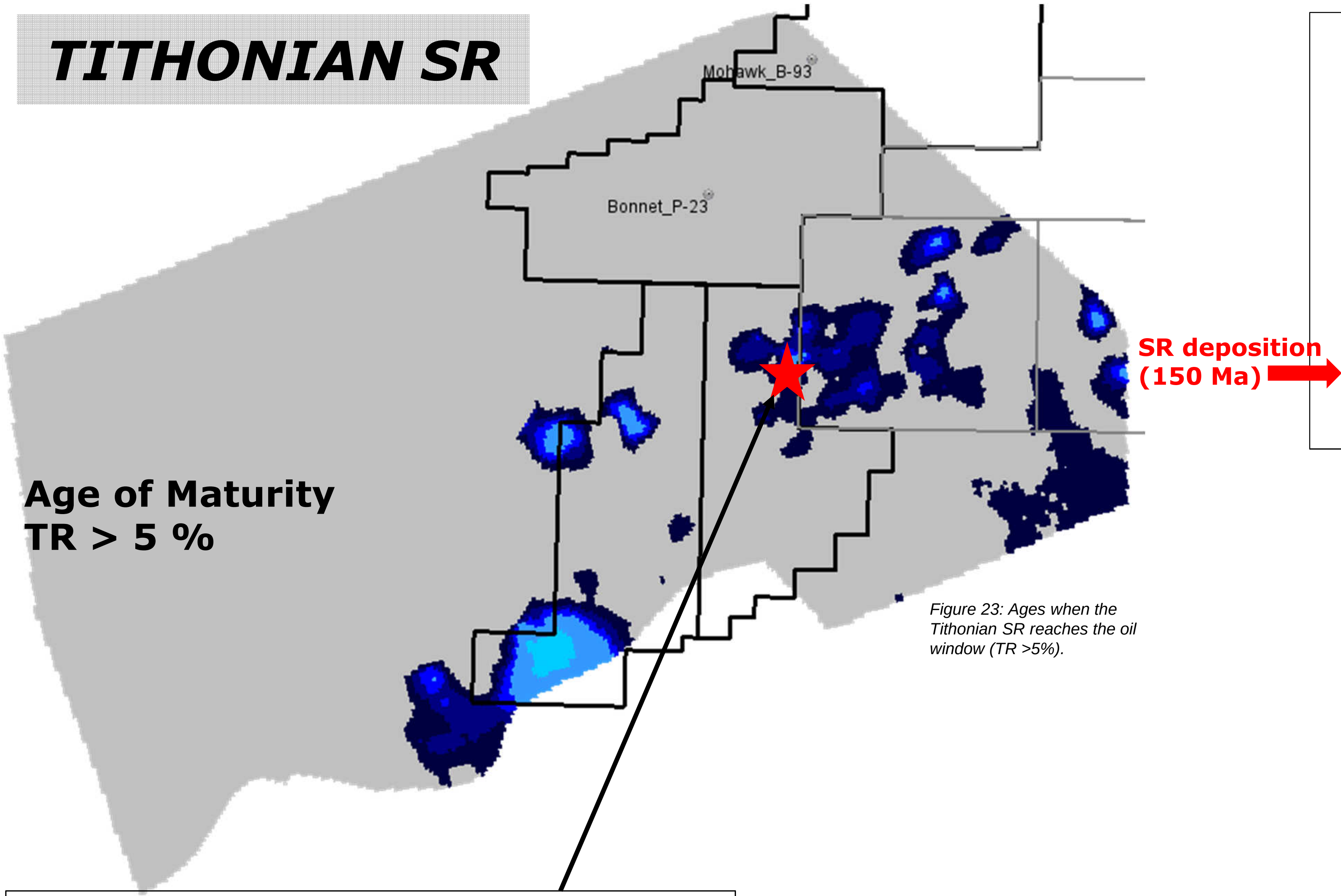


Figure 22: Transformation ration of Tithonian SR.

TITHONIAN SR



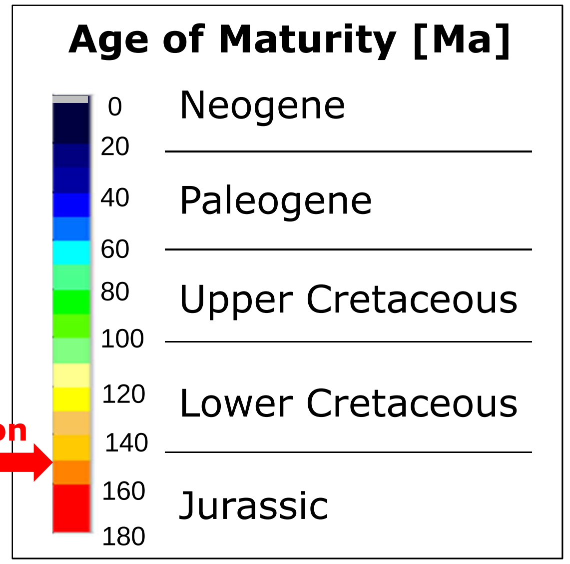
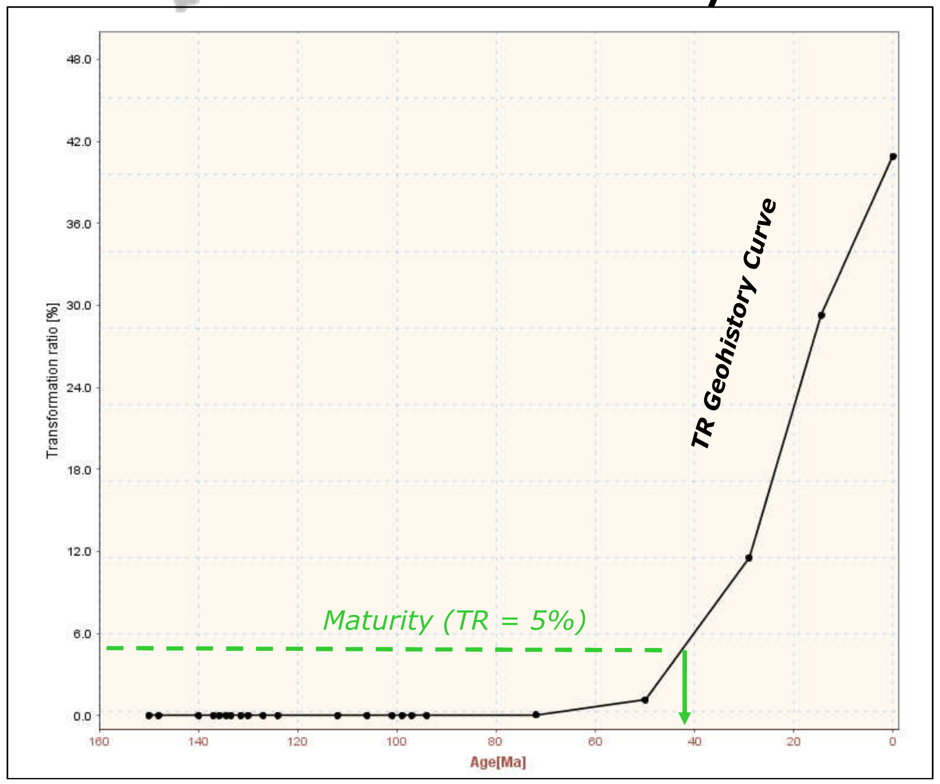


Figure 23: Ages when the Tithonian SR reaches the oil window (TR >5%).

Age of maturity and of over-maturity (in Million Years)

The map indicates the age at which the source rock reached a given level of maturity: 5% of Transformation Ratio for the beginning of maturity (oil window).

Maturation of the Tithonian SR (Figure 23) started near 70-60 Ma in the mini-basins and south limit. The SR is not mature in the other areas.



Evolution of the Maturity

The graph indicates the evolution of the Transformation Ratio through time in the area where Tithonian SR reaches 5% of transformation ratio (Figures 23 and 24).

The important burial episode beginning near 70Ma is observable on this TR vs Age curve, with an augmentation of the TR at this period that can reach the 40% in the deepest parts of the basin.

Figure 24: TR evolution through time of the Tithonian SR.

Vitrinite at Present Day

The vitrinite map is computed from the EasyRo in %. The vitrinite, as the TR maps shows us an immature SR which haves vitrinite values of 0.6-1% (Figure 25).

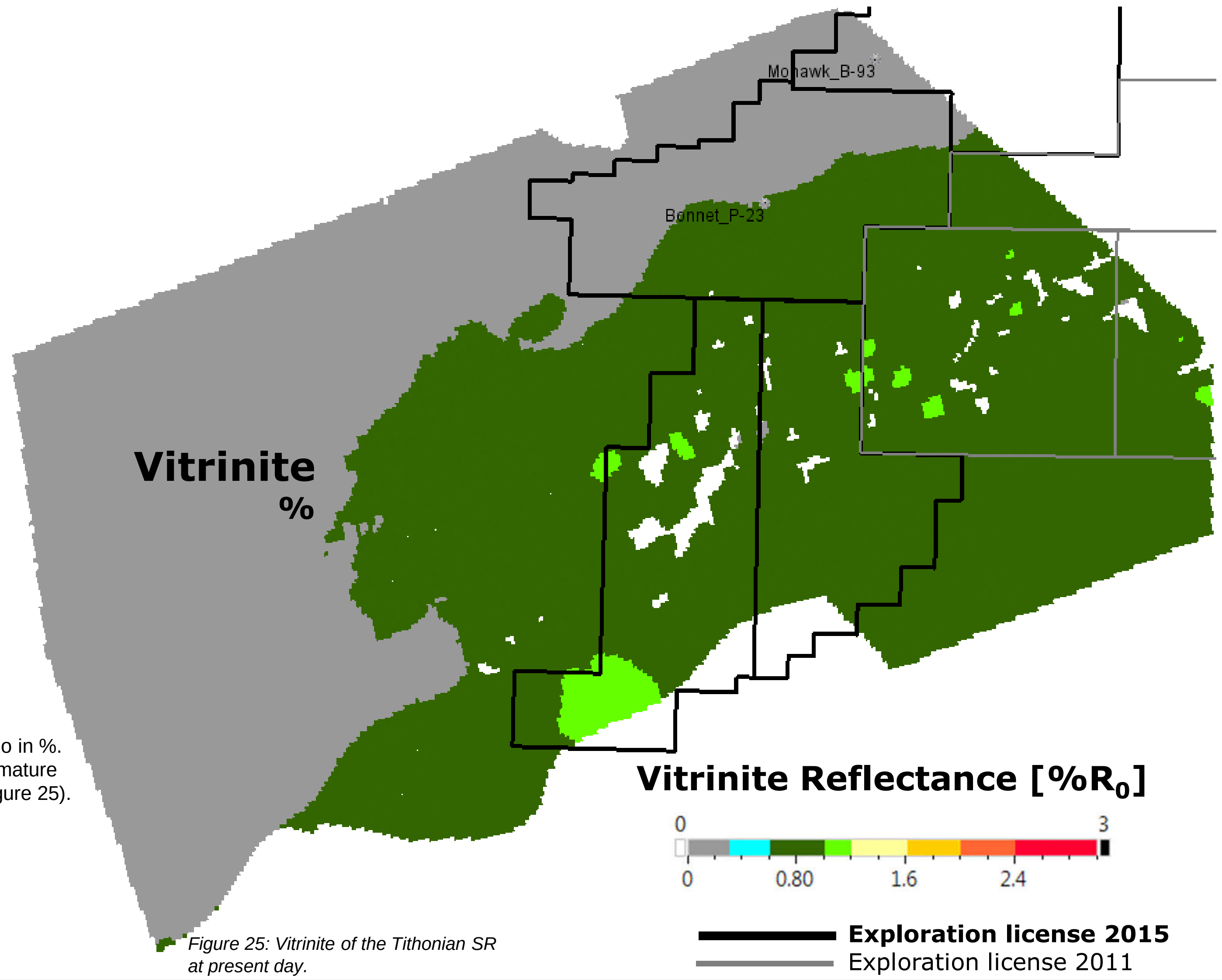
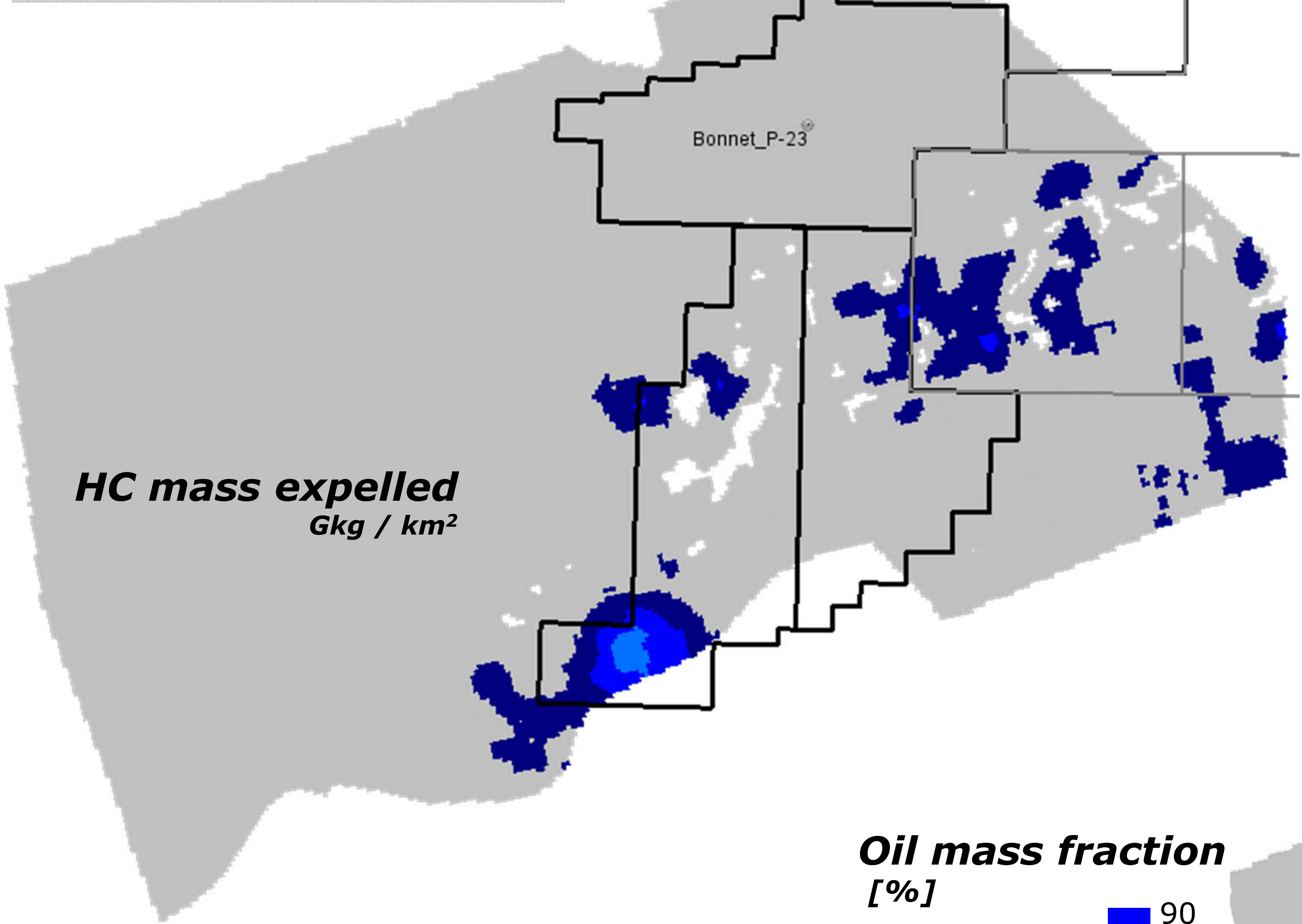


Figure 25: Vitrinite of the Tithonian SR at present day.

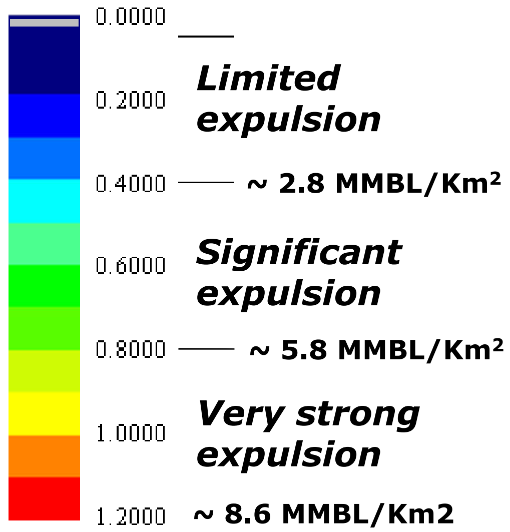
TITHONIAN SR



HC mass expelled

[Gkg / km²]

1 Gkg = 10⁹ kg = 1 Million T
~ 7.2 Mbbl



Exploration license 2015
Exploration license 2011

Figure 26: Summary of HC mass expelled for the Valanginian SR.

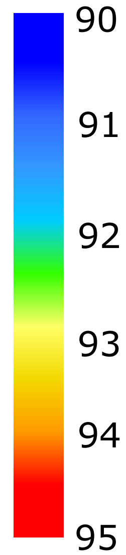
Expulsion Map at Present Day

The map gives HC mass expelled through time (cumulated mass).
HC mass expelled = oil mass expelled + gas mass expelled
Expulsion process corresponds to primary migration of HC out of SR layers.
Expelled volumes are smaller than generated volumes and depend on petrophysical properties of source rocks (porosity, relatives permeability between hydrocarbons and water, irreducible water saturation, capillary pressure, etc.).
Locally, the source rock can be slightly mature without expulsion.
In that study case, it is unlikely that zones with expulsion lower than 400 Gkg / km2 significantly contribute to an active petroleum system.
To convert HC mass (Gkg) in equivalent barrels of oil , multiply values by about 7,2 (average oil density estimated at 810 kg/m3).

For the Tithonian SR, expulsion mainly occurs in mini-basins (Figure 26) but the quantity never exceeds the limit to consider the participation of this source rock to the system (limited expulsion).

Oil mass fraction

[%]



OIL /TOTAL HC Ratio Map at Present Day (in percent)

The map gives the fraction of oil expelled by the source rock through time: ratio = mass of expelled oil / total mass of expelled HC.
This ratio doesn't take into account secondary cracking of heavy HC occurring within the source rock layer as we consider that it occurs during migration (secondary cracking in the SR can be neglected due to the temperature and the amount of quantities affected).
.

The Tithonian SR expelled more oil than gas, its ratio oil/gas is equal to 95% oil (Figure 27) where HCs are expelled.

Exploration license 2015
Exploration license 2011

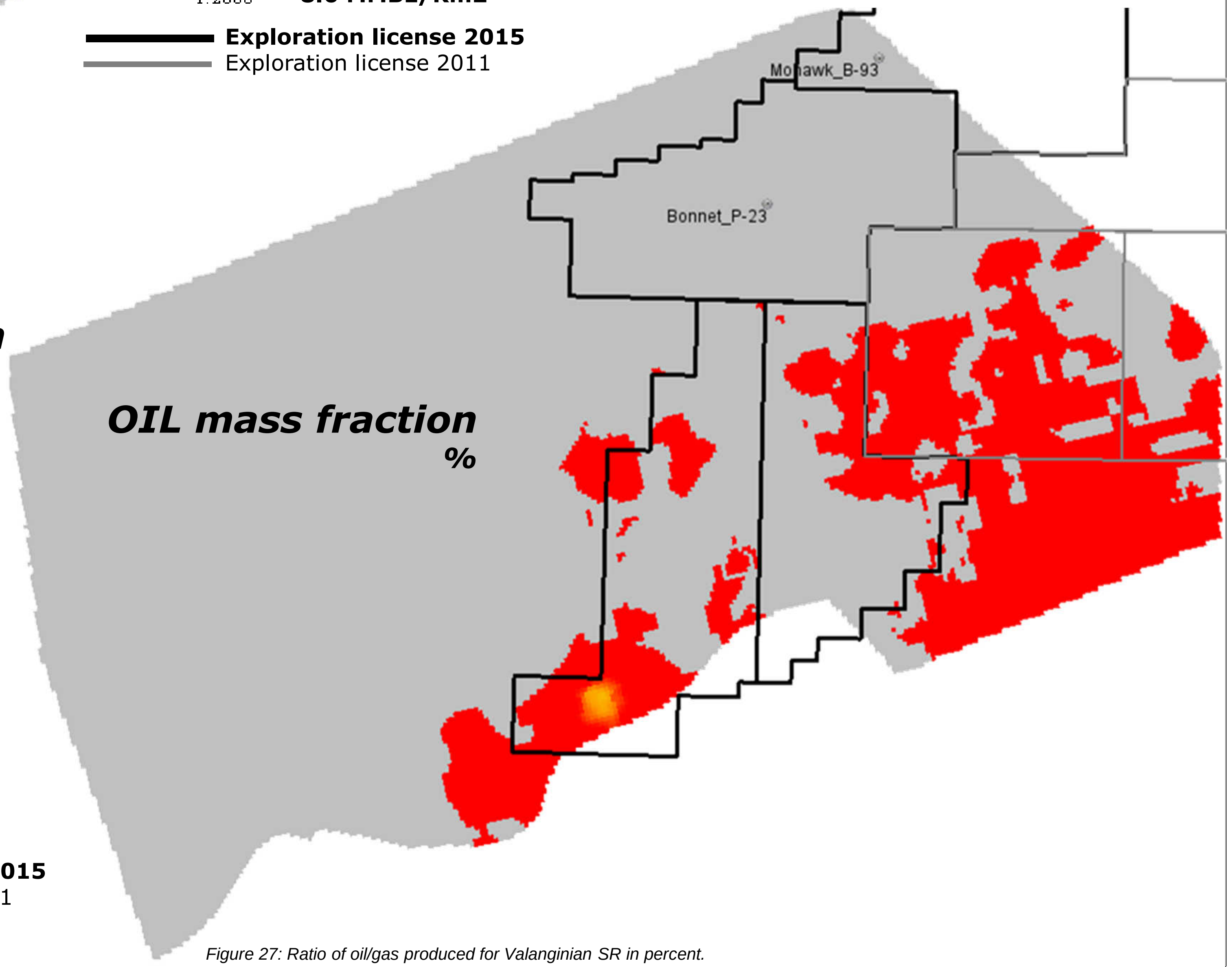


Figure 27: Ratio of oil/gas produced for Valanginian SR in percent.

CALLOVIAN SR

APTIAN SR
VALANGINIAN SR
TITHONIAN SR
CALLOVIAN SR (≈ 163 Ma)
Low Jurassic Complex SR

Relationship TR / Vitrinite	TR = 5% Maturity (oil window)	TR = 50 %	TR = 95 % Overmaturity
Kerogen Type II	$VR_0 = 0.7$	$VR_0 = 0.9$	$VR_0 = 2$

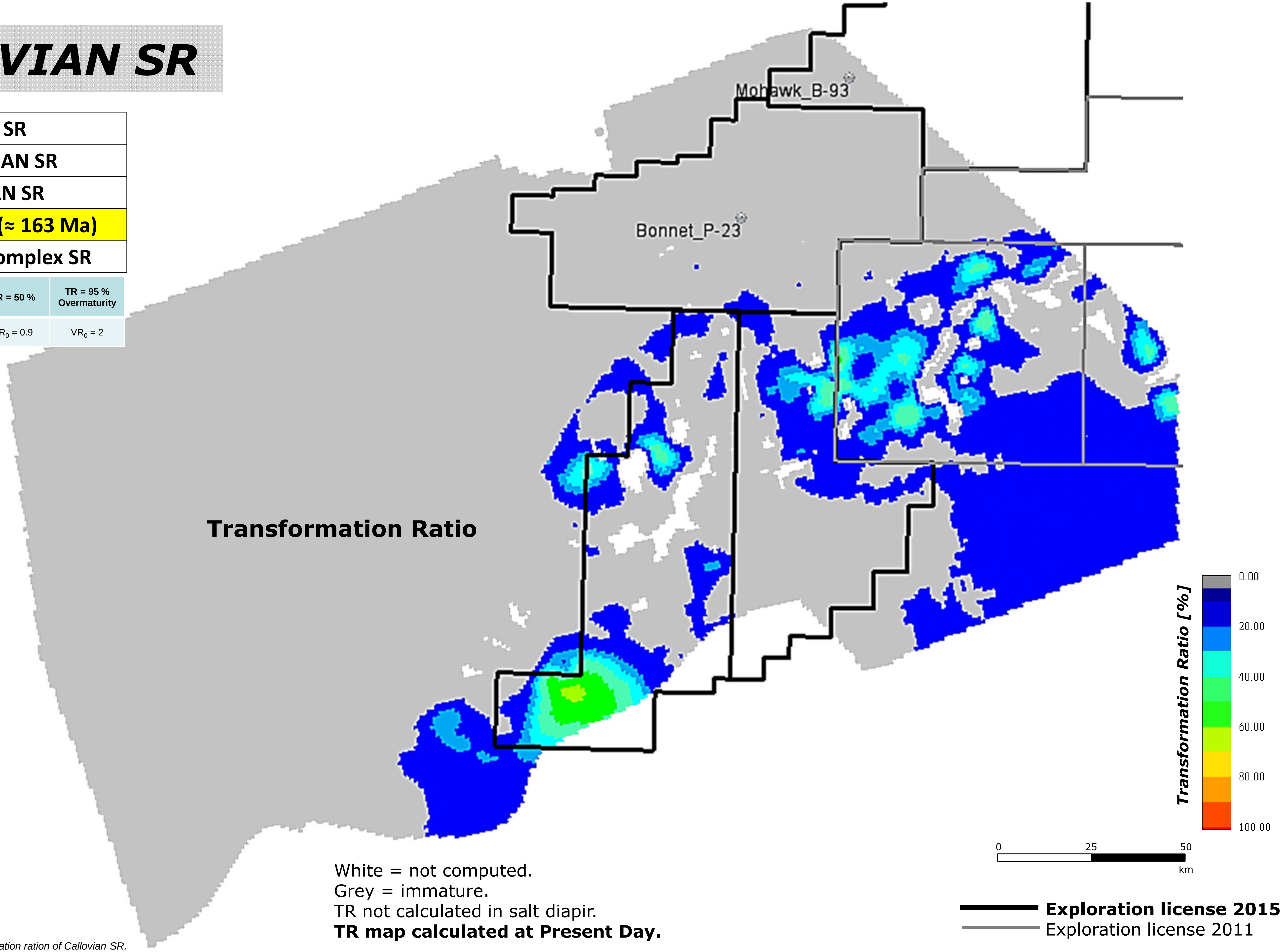


Figure 28: Transformation ration of Callovian SR.

CALLOVIAN SR

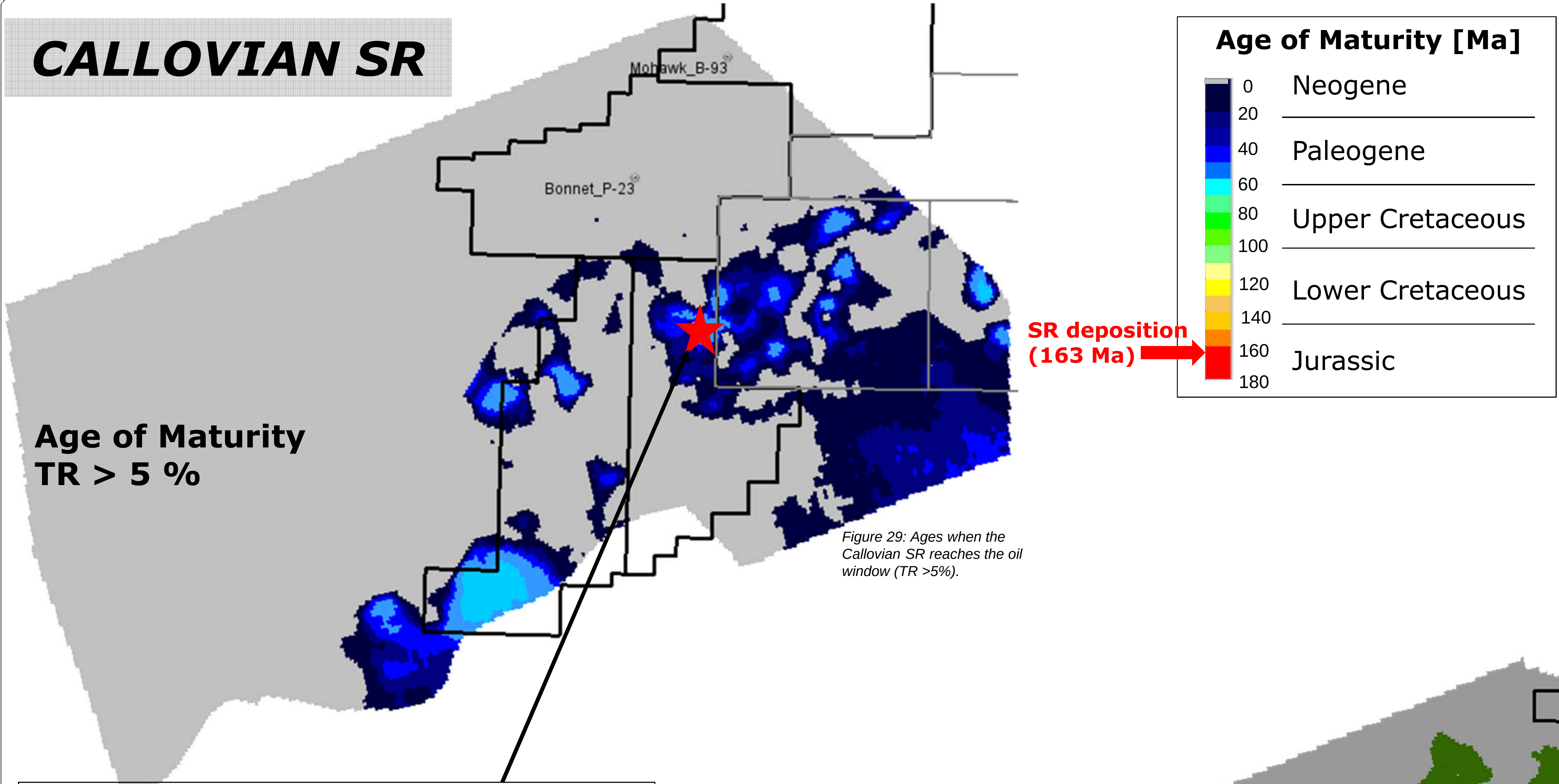


Figure 29: Ages when the Callovian SR reaches the oil window (TR >5%).

Age of maturity and of over-maturity (in Million Years)

The map indicates the age at which the source rock reached a given level of maturity: 5% of Transformation Ratio for the beginning of maturity (oil window).

Maturation of the Callovian SR (Figure 29) started near 70-60 Ma in the mini-basins and south limit, like Tithonian SR. The SR is not mature in the other areas.

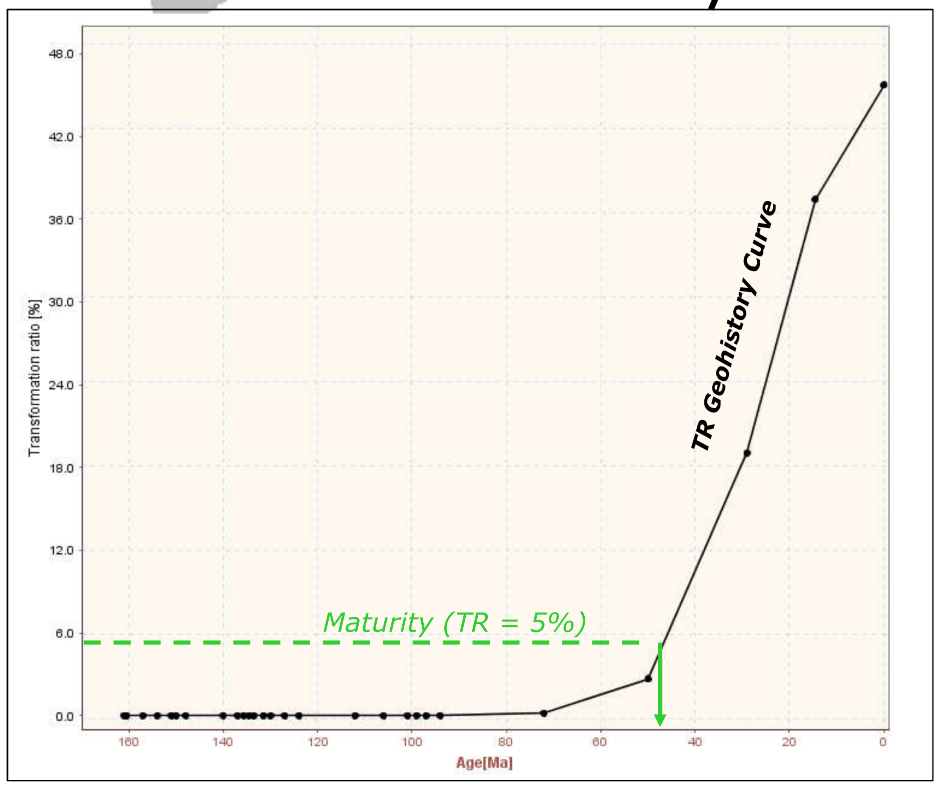


Figure 30: TR evolution through time of the Callovian SR.

Evolution of the Maturity

The graph indicates the evolution of the Transformation Ratio through time in the area where CallovianSR reach 5% of transformation ratio (Figures 29 and 30).

The important burial episode beginning near 70Ma is observable on this TR vs Age curve, with an augmentation of the TR at this period that can reach the 40% in the deepest parts of the basin.

Vitrinite at Present Day

The vitrinite map is computed from the EasyRo in %. The vitrinite, as the TR maps shows us an immature SR which haves vitrinite values of 0.6-1%. It reaches the 1–1,2% in the mini-basins and the south limit (Figure31).

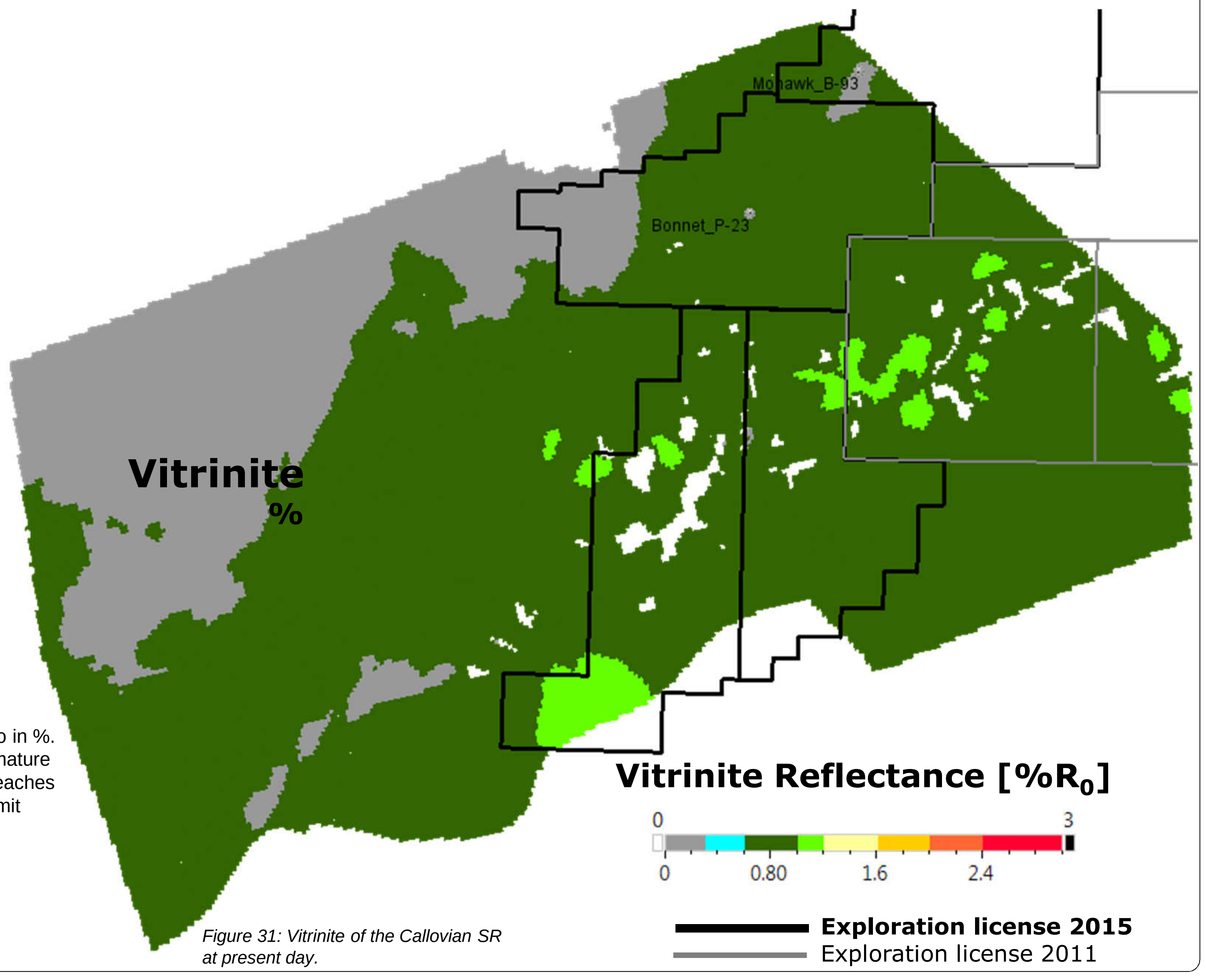


Figure 31: Vitrinite of the Callovian SR at present day.

CALLOVIAN SR

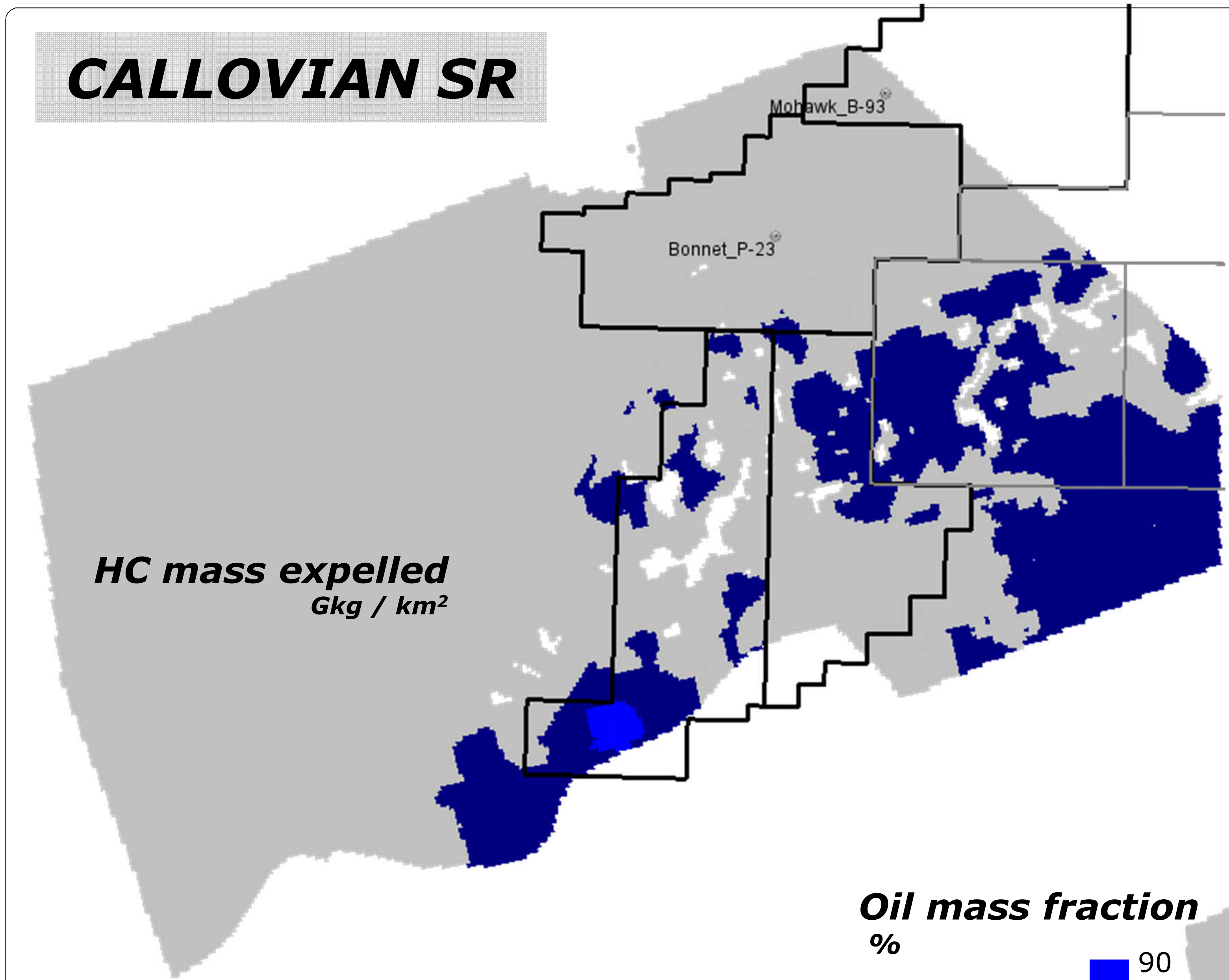
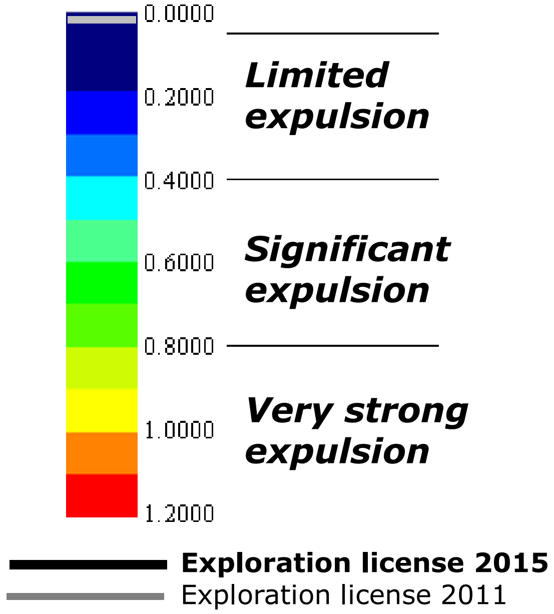


Figure 32: Summary of HC mass expelled for the Callovian SR.

HC mass expelled

Gkg / km^2

1 Gkg = 10^9 kg = 1 Million T ~ 7.2 Mbbl



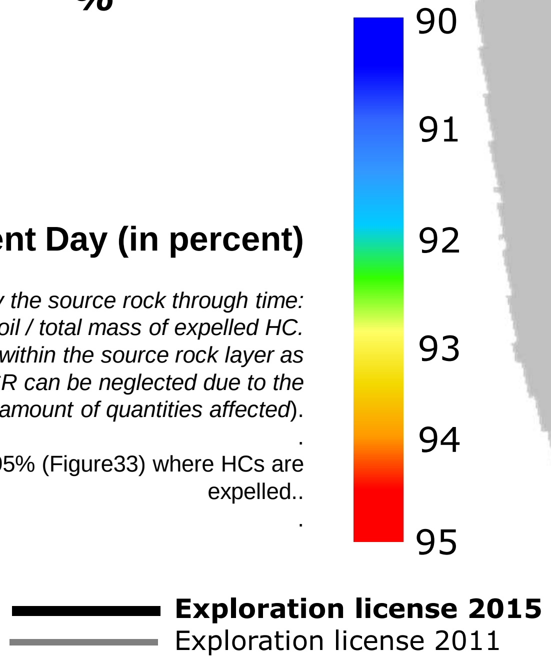
Expulsion Map at Present Day

The map gives HC mass expelled through time (cumulated mass).
HC mass expelled = oil mass expelled + gas mass expelled
Expulsion process corresponds to primary migration of HC out of SR layers.
Expelled volumes are smaller than generated volumes and depend on petrophysical properties of source rocks (porosity, relatives permeability between hydrocarbons and water, irreducible water saturation, capillary pressure, etc.).
Locally, the source rock can be slightly mature without expulsion.
In that study case, it is unlikely that zones with expulsion lower than 400 Gkg / km2 significantly contribute to an active petroleum system.
To convert HC mass (Gkg) in equivalent barrels of oil , multiply values by about 7,2 (average oil density estimated at 810 kg/m3).

For the Callovian SR (Figure 32) (which TOC is lower than Tithonian SR), expulsion mainly occurs in mini-basins but the quantity never exceeds the limit to consider the participation of this source rock in the system (limited expulsion).

Oil mass fraction

%



OIL /TOTAL HC Ratio Map at Present Day (in percent)

The map gives the fraction of oil expelled by the source rock through time:
ratio = mass of expelled oil / total mass of expelled HC.
This ratio doesn't take into account secondary cracking of heavy HC occurring within the source rock layer as we consider that it occurs during migration (secondary cracking in the SR can be neglected due to the temperature and the amount of quantities affected).

The Callovian SR expelled more oil than gas, its ratio oil/gas is equal to 95% (Figure33) where HCs are expelled..

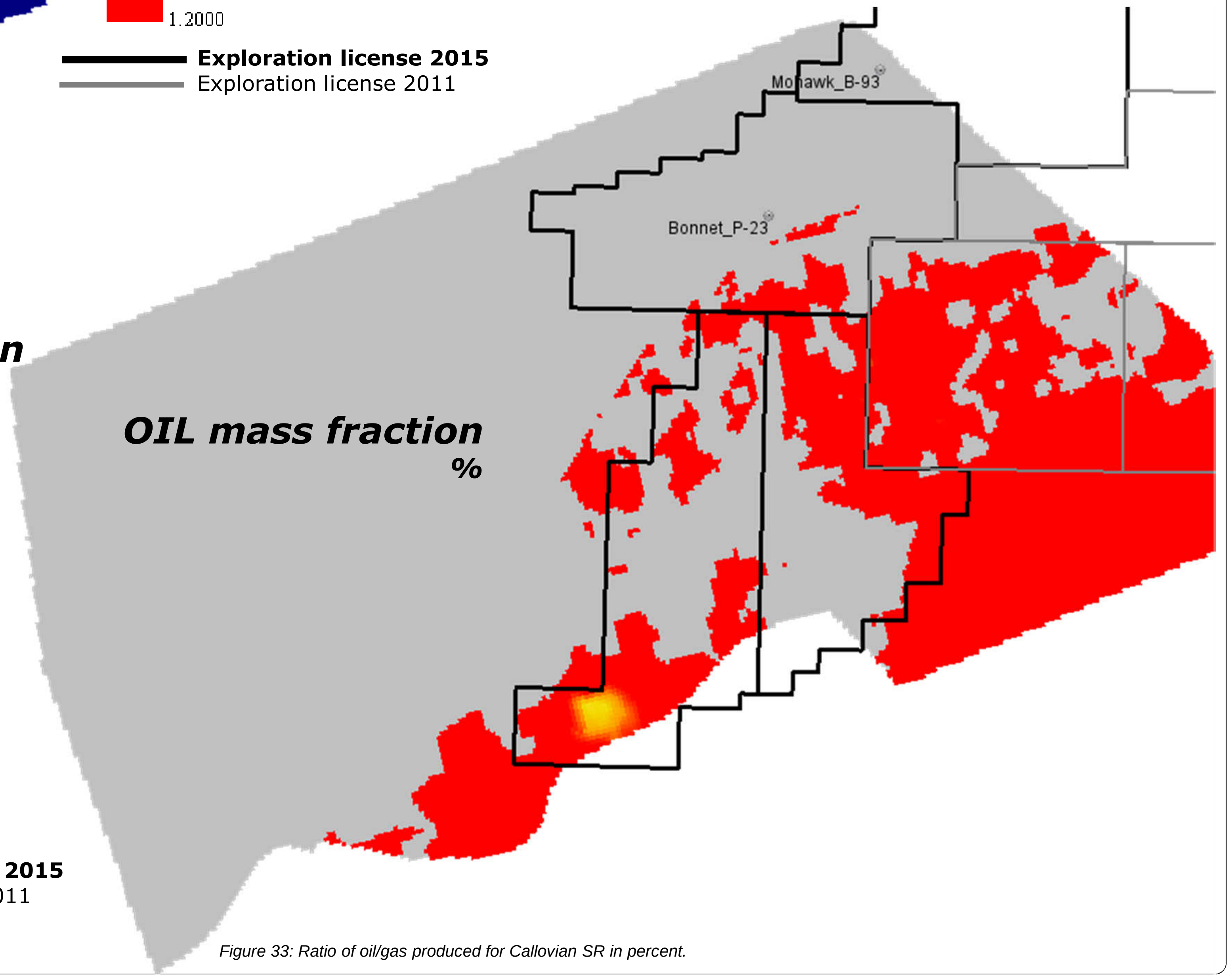


Figure 33: Ratio of oil/gas produced for Callovian SR in percent.

Low Jurassic Complex SR

APTIAN SR
VALANGINIAN SR
TITHONIAN SR
CALLOVIAN SR
Low Jurassic SR (≈ 196 Ma)

Relationship TR / Vitrinite	TR = 5% Maturity (oil window)	TR = 50 %	TR = 95 % Overmaturity
Kerogen Type II	VR_0 = 0.7	VR_0 = 0.9	VR_0 = 2

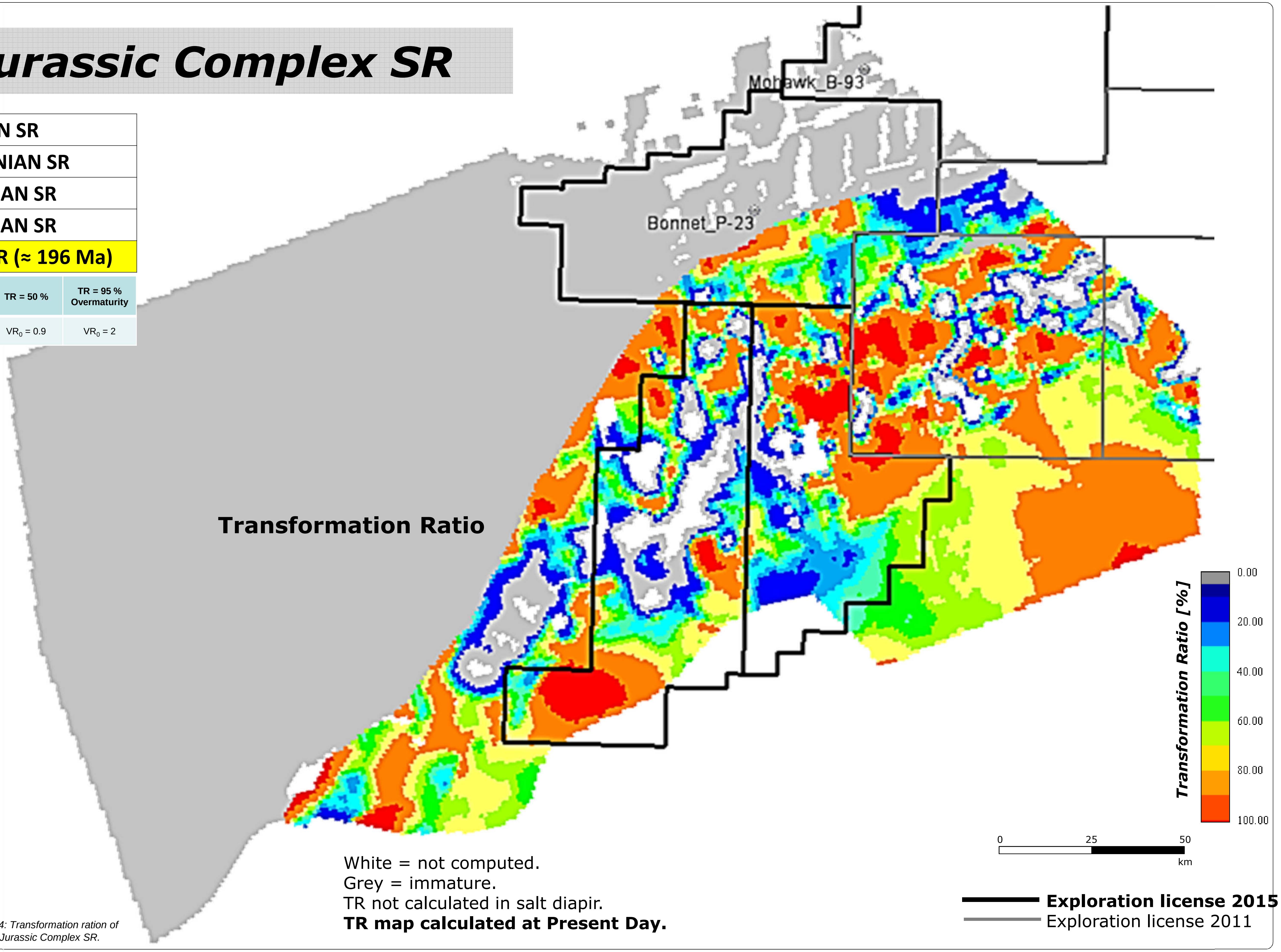


Figure 34: Transformation ration of the Low Jurassic Complex SR.

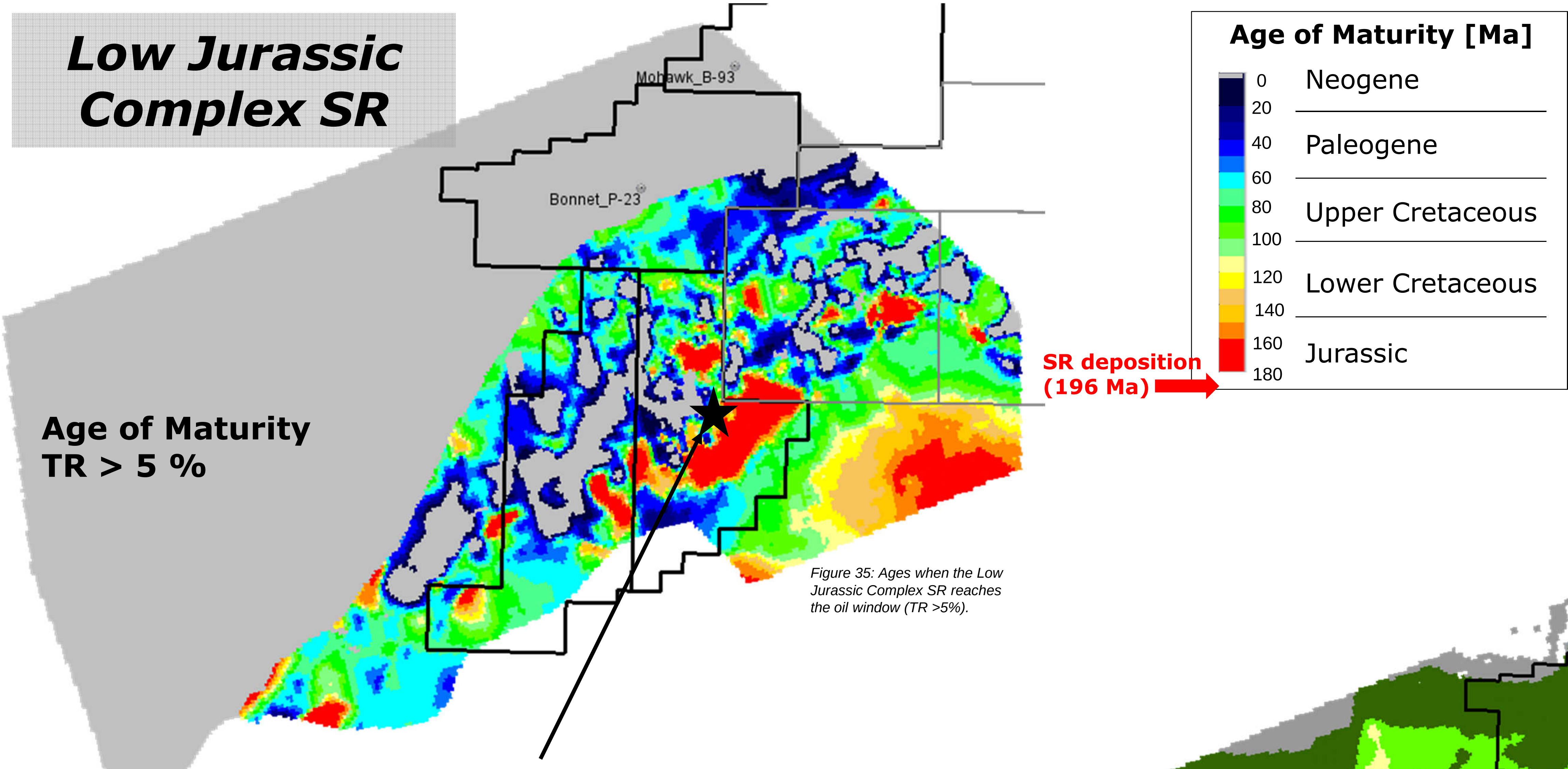


Figure 35: Ages when the Low Jurassic Complex SR reaches the oil window (TR >5%).

Age of maturity and of over-maturity (in Million Years)

The map indicates the age at which the source rock reached a given level of maturity: 5% of Transformation Ratio for the beginning of maturity (oil window).

Maturation of the Low Jurassic Complex SR (Figure 35) started near 170-160Ma in the mini-basins. The most parts of the source rock reach the 5% at 80Ma except lower parts that reach this value near 40-20Ma.

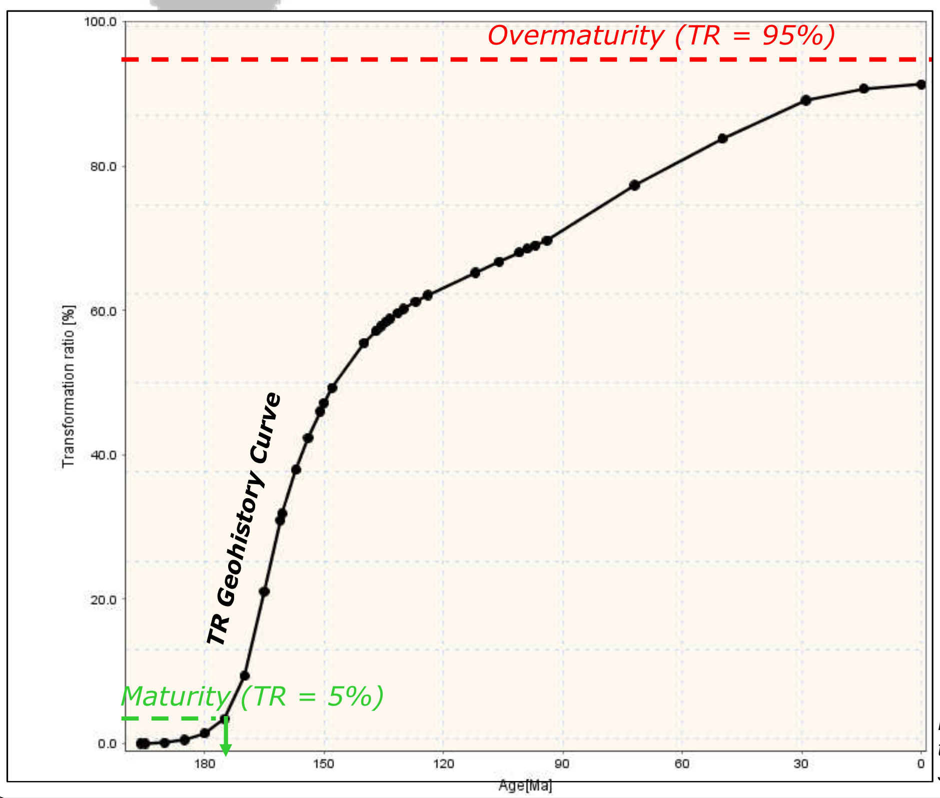


Figure 36: TR evolution through time of the Low Jurassic Complex SR.

Evolution of the Maturity

The graph indicates the evolution of the Transformation Ratio through time in the area where Lower Jurassic SR reach 5% of transformation ratio (Figures 35 and 36).

The important burial episode beginning near 70Mais less observable, as this source rock is early mature.
The augmentation of the Transformation ratio is observable from 160 to 120Ma where we reach 60% of TR in deepest parts, due to the cooling effect of the rifting event (ends at 197Ma). The TR continue to increase until 90% at 30Ma.

Vitrinite at Present Day

The vitrinite map is computed from the EasyRo in %. The vitrinite (Figure 37), as the TR maps shows us a mature source rock mostly in the oil window (%Ro>1) with some areas that reach the gas window.

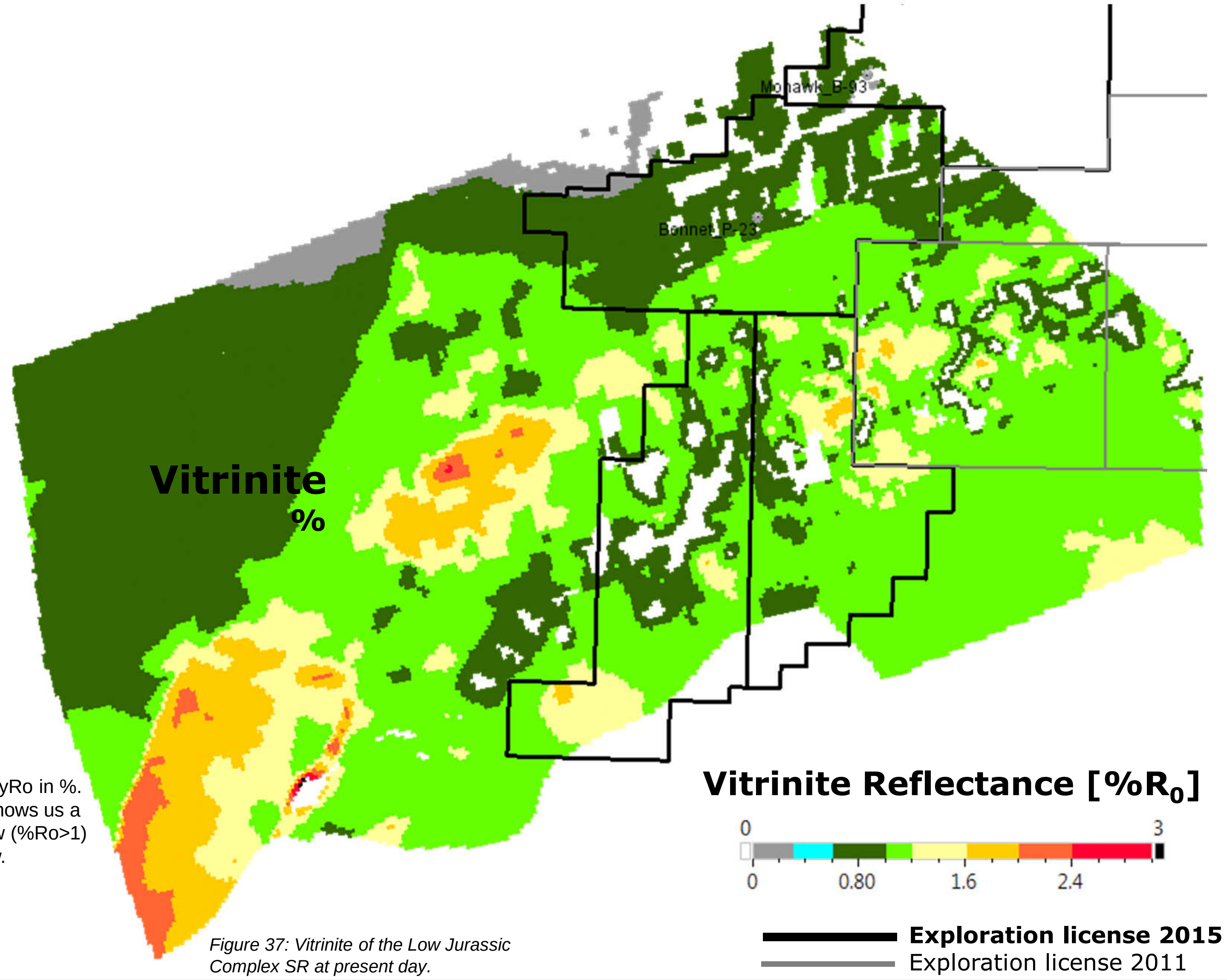


Figure 37: Vitrinite of the Low Jurassic Complex SR at present day.

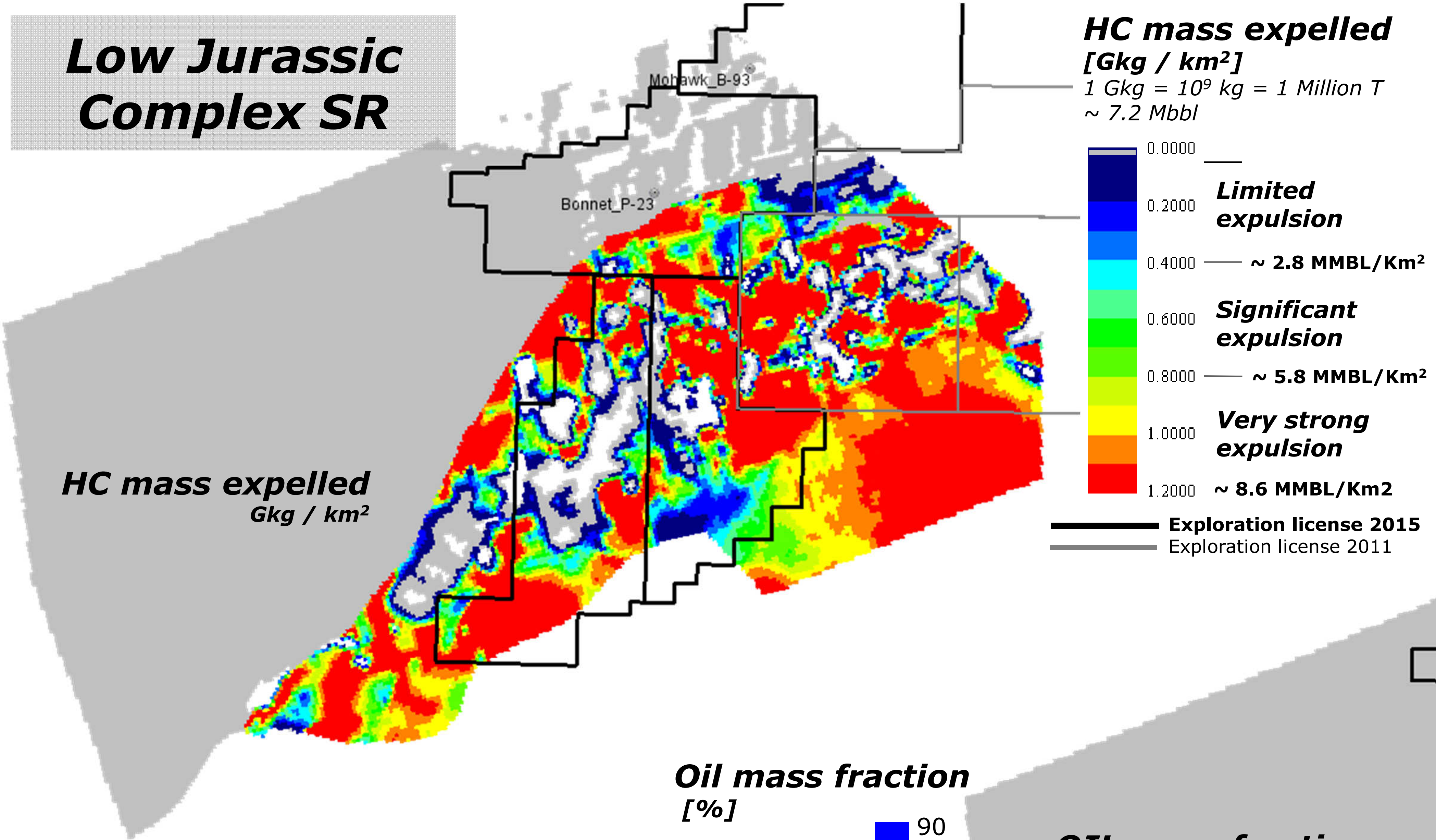


Figure 38: Summary of HC mass expelled for the Low Jurassic Complex SR.

Expulsion Map at Present Day

The map gives HC mass expelled through time (cumulated mass).
HC mass expelled = oil mass expelled + gas mass expelled
Expulsion process corresponds to primary migration of HC out of SR layers.
Expelled volumes are smaller than generated volumes and depend on petrophysical properties of source rocks (porosity, relatives permeability between hydrocarbons and water, irreducible water saturation, capillary pressure, etc.).
Locally, the source rock can be slightly mature without expulsion.
In that study case, it is unlikely that zones with expulsion lower than 400 Gkg / km2 significantly contribute to an active petroleum system.
To convert HC mass (Gkg) in equivalent barrels of oil , multiply values by about 7,2 (average oil density estimated at 810 kg/m3).

For the Low Jurassic Complex SR (Figure 38) expulsion exceeds 1200 Gkg/km². in the whole area expulsion is also very important, we can consider that this SR haves a key role in the petroleum system of this basin.

OIL /TOTAL HC Ratio Map at Present Day (in percent)

The map gives the fraction of oil expelled by the source rock through time:
ratio = mass of expelled oil / total mass of expelled HC.
This ratio doesn't take into account secondary cracking of heavy HC occurring within the source rock layer as we consider that it occurs during migration (secondary cracking in the SR can be neglected due to the temperature and the amount of quantities affected).

As Vitrinite map shown us, the Low Jurassic Complex SR expelled more oil than gas (Figure 39).
The Low Complex Jurassic SR is an oil prone SR (TY II).
The oil mass fraction is close to 95% in all the SR, except in the lower parts where it can reach the 90%.

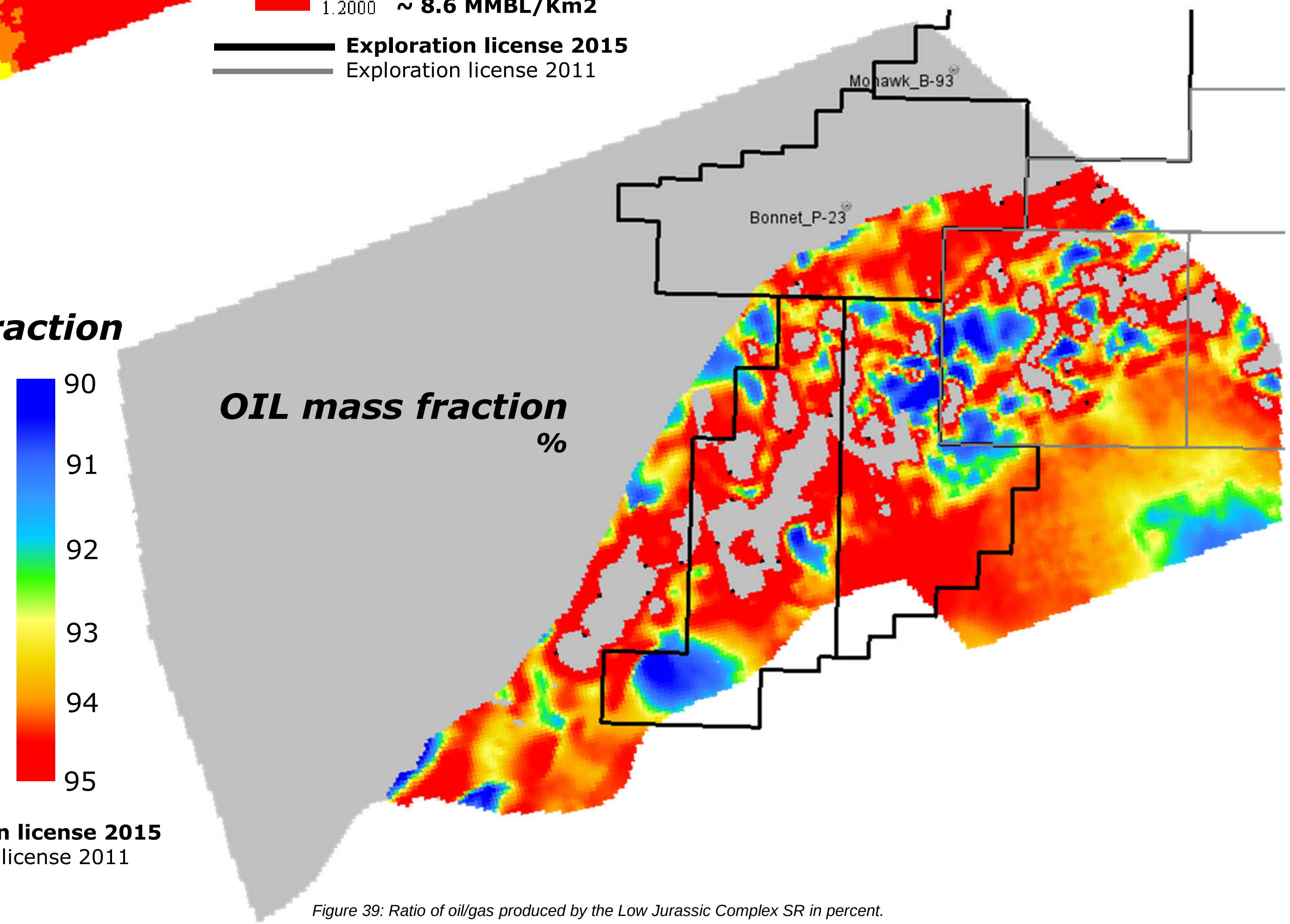


Figure 39: Ratio of oil/gas produced by the Low Jurassic Complex SR in percent.

	Total OIL-Heavy Expelled Mass Cell [Gkg]	Total OIL-Normal Expelled Mass Cell [Gkg]	Total OIL-Condensate Expelled Mass Cell [Gkg]	Total GAS-Thermogenic Expelled Mass Cell [Gkg]	Total C1-biogenique Expelled Mass Cell [Gkg]	Total mass of HC expelled [Gkg] in oil equivalent	Total mass of Oil expelled [BB bbl]	Total mass of Gas expelled [tcf]	Total mass of HC expelled [billion bbl] in oil equivalent
All SR	**4387,00**	**6857,00**	**1964,00**	**931,80**	**0,00**	**14139,80**	**95,0976**	**46,59**	**101,8066**
Aptian	0,02	0,03	0,01	0,01	0,00	0,06	0,0004077	0,000259	0,000445
Valanginian	0,03	0,05	0,02	0,01	0,00	0,11	0,000680688	0,000552	0,00076
Tithonian	94,47	154,70	34,90	15,62	0,00	299,69	2,045304	0,781	2,157768
Callovian	120,50	198,80	45,16	20,07	0,00	384,53	2,624112	1,0035	2,768616
Low Jurrasic Complex SR	**4172,00**	**6503,00**	**1884,00**	**896,10**	**0,00**	**13455,10**	**90,4248**	**44,805**	**96,87672**

Table 8: Total of expelled components for each SR.

Expelled HC masses - By SOURCE ROCK (Table 8, Figures 40 and 41)

This ratio doesn't take into account secondary cracking of heavy HC occurring within the source rock layer as we consider that it occurs during migration (secondary cracking in the SR can be neglected due to the temperature and the amount of quantities affected).

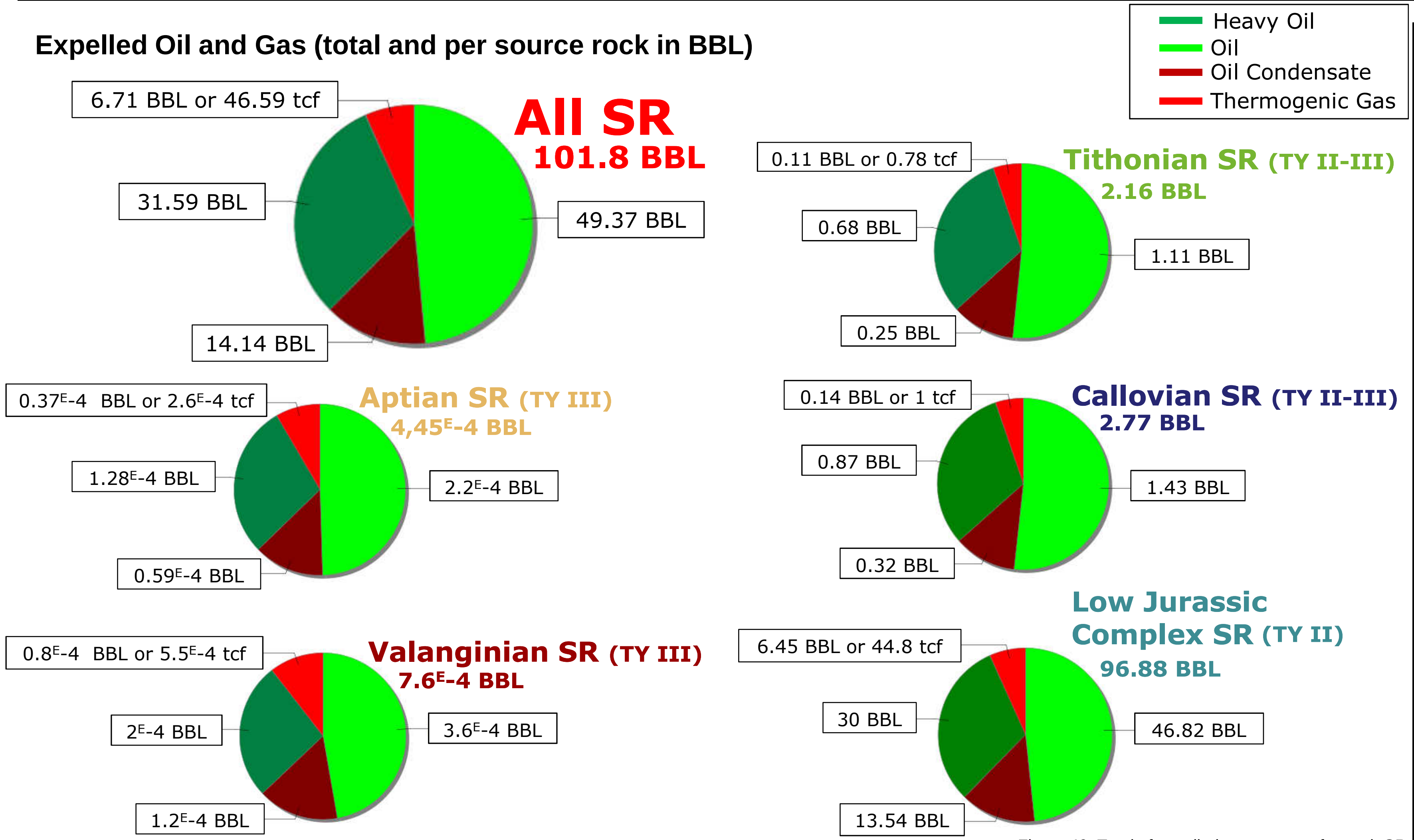


Figure 40: Total of expelled components for each SR.

Expelled HC volume by SR and Total

Figure 41 shows the contribution of the Low Jurassic Complex SR in the system is very important, Tithonian and Callovian SR can be taken into account and others can be neglected.

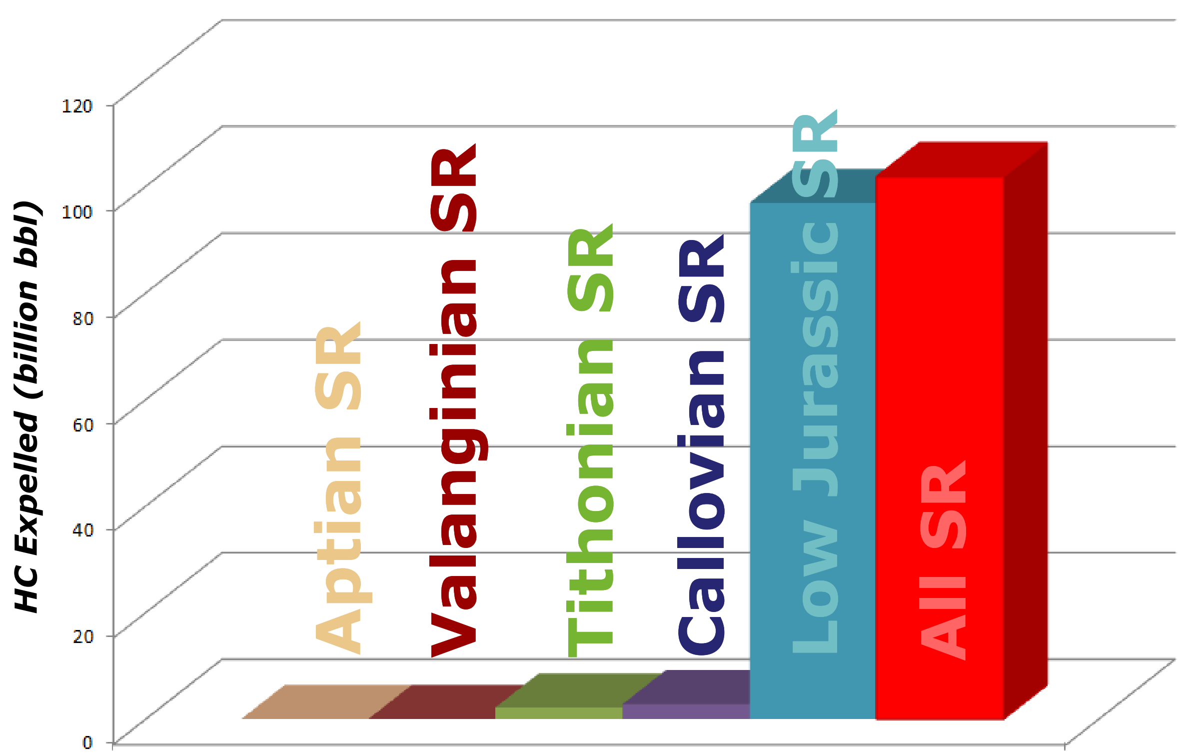
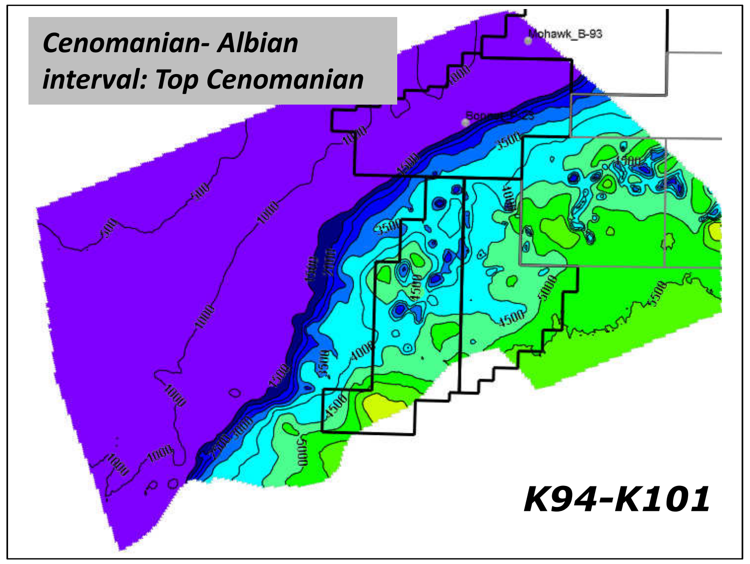
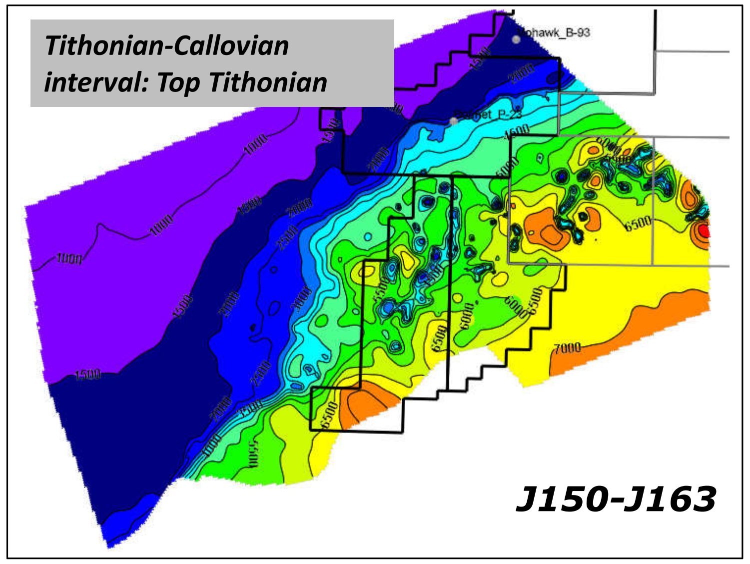


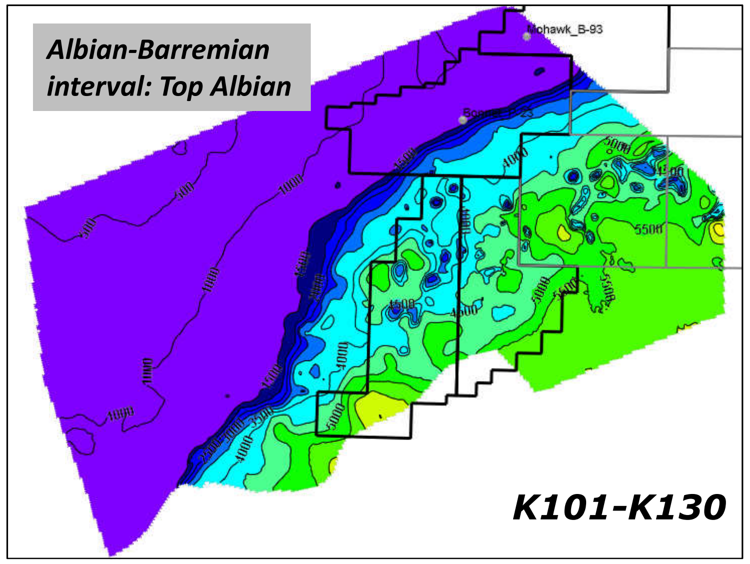
Figure 41: Contribution to the Petroleum System of each SR.

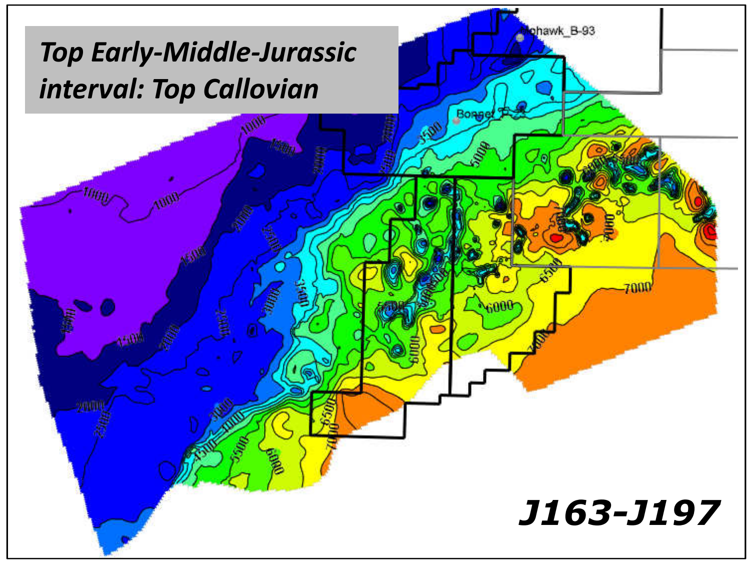
CHAPTER 7.3

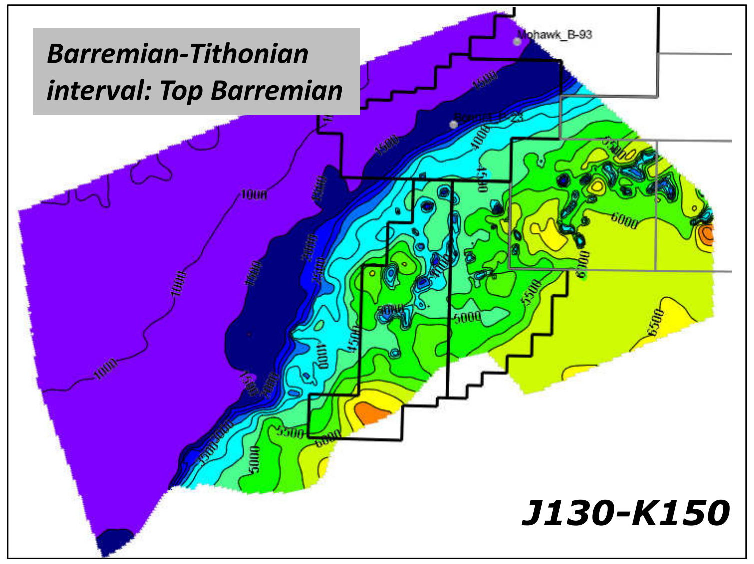
BASIN MODELING – MIGRATION SIMULATION











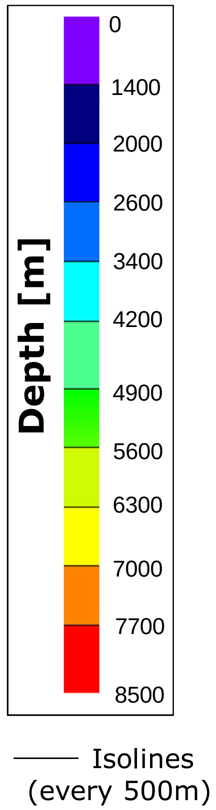
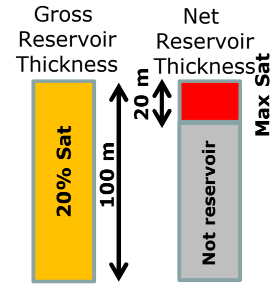


Figure 42: Top horizons of the stratigraphic intervals (reservoirs) considered in the study.

5 Reservoir intervals in the 3D Block.

Regarding the data available to build the model (seismic + 2 wells + Dionisos® model), we suggest to consider 5 reservoir intervals (Figure 42 and Table 9). An analyse of each of them will be performed separately after simulations.

For each of these intervals, reservoir facies were defined with a maximum of HC saturation of 20% to simulate the net reservoir thickness (Figure 43).



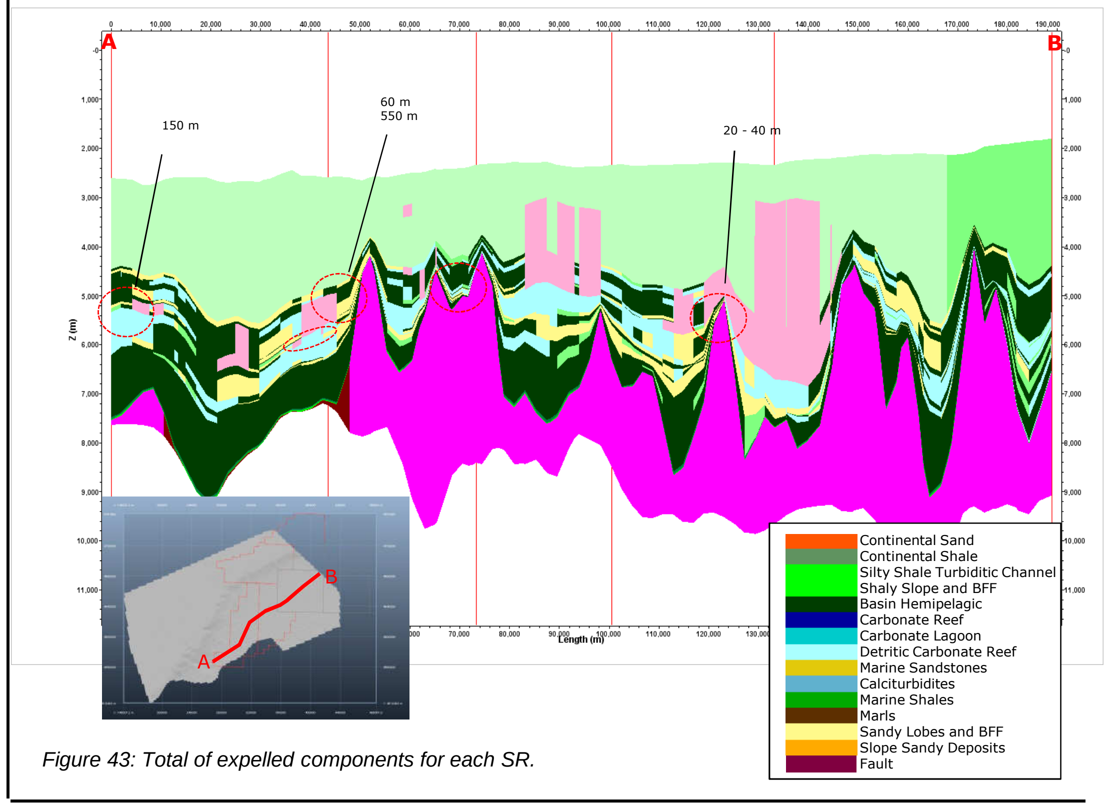


Figure 43: Total of expelled components for each SR.

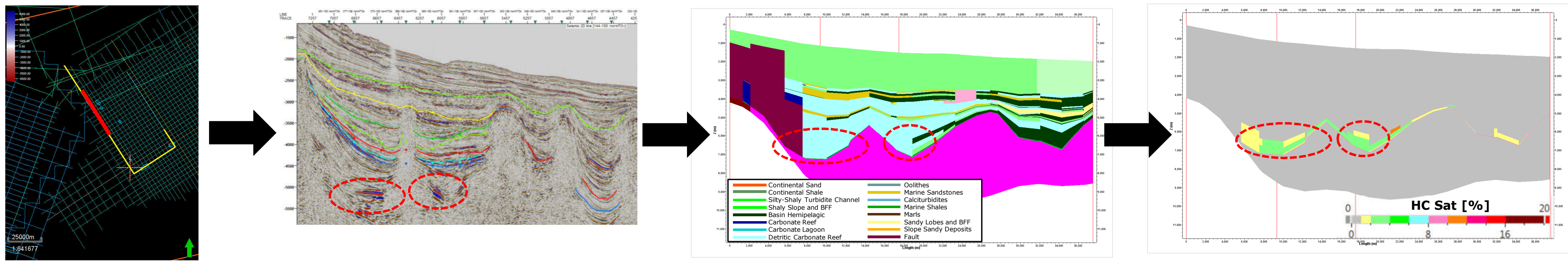
Stratigraphic Interval	Age Interval	Reservoir Facies	Porosity Range
Cenomanian-Albian	101-94 Ma	Calciturbidites, detritic carbonates and Sandy turbidites.	Sandstone on the platform keeps a high porosity. In the basin, the reservoirs have a porosity of 10-15%,for carbonates and 14-20% for sandstones
Albian-Barremian	130-101 Ma	Calciturbidites, detritic carbonates and Sandy turbidites.	Sandstone on the platform keeps a high porosity. In the basin, the reservoirs have a porosity of 10-15%,for carbonates and sandstones
Barremian-Tithonian	150-130 Ma	Calciturbidites, detritic carbonates and Sandy turbidites.	Sandstone on the platform keeps a high porosity. In the basin, the reservoirs have a porosity of 10-15%,for carbonates and sandstones
Tithonian-Callovian	163-150 Ma	Calciturbidites, detritic carbonates and Sandy turbidites.	Sandstone on the platform keeps a high porosity on the platform. In the basin, the reservoirs have a porosity of 9-13%.
Early-Middle-Jurassic	197-163 Ma	Carbonate Breccia, Reef facies, Detritic carbonate deposits and Sandy turbidites basinward.	Sandstone on the platform keeps a high porosity on the platform. In the basin, the reservoirs have a porosity of 6-11% (10% for carbonate breccia).

Table 9: Description of stratigraphic intervals (reservoirs) considered.

Calibration using Hydrocarbon indices

The migration model is calibrated using hydrocarbon indices (flatspot) seen on the 2D seismic. The model ties to accumulate HCs in the area of stratigraphic interval where flatspots were detected. HCs accumulations are mostly located in traps (stratigraphic or salt related traps) in these intervals and some of these traps show the presence of flatspots.

Figures 44 and 45 show some exemples.



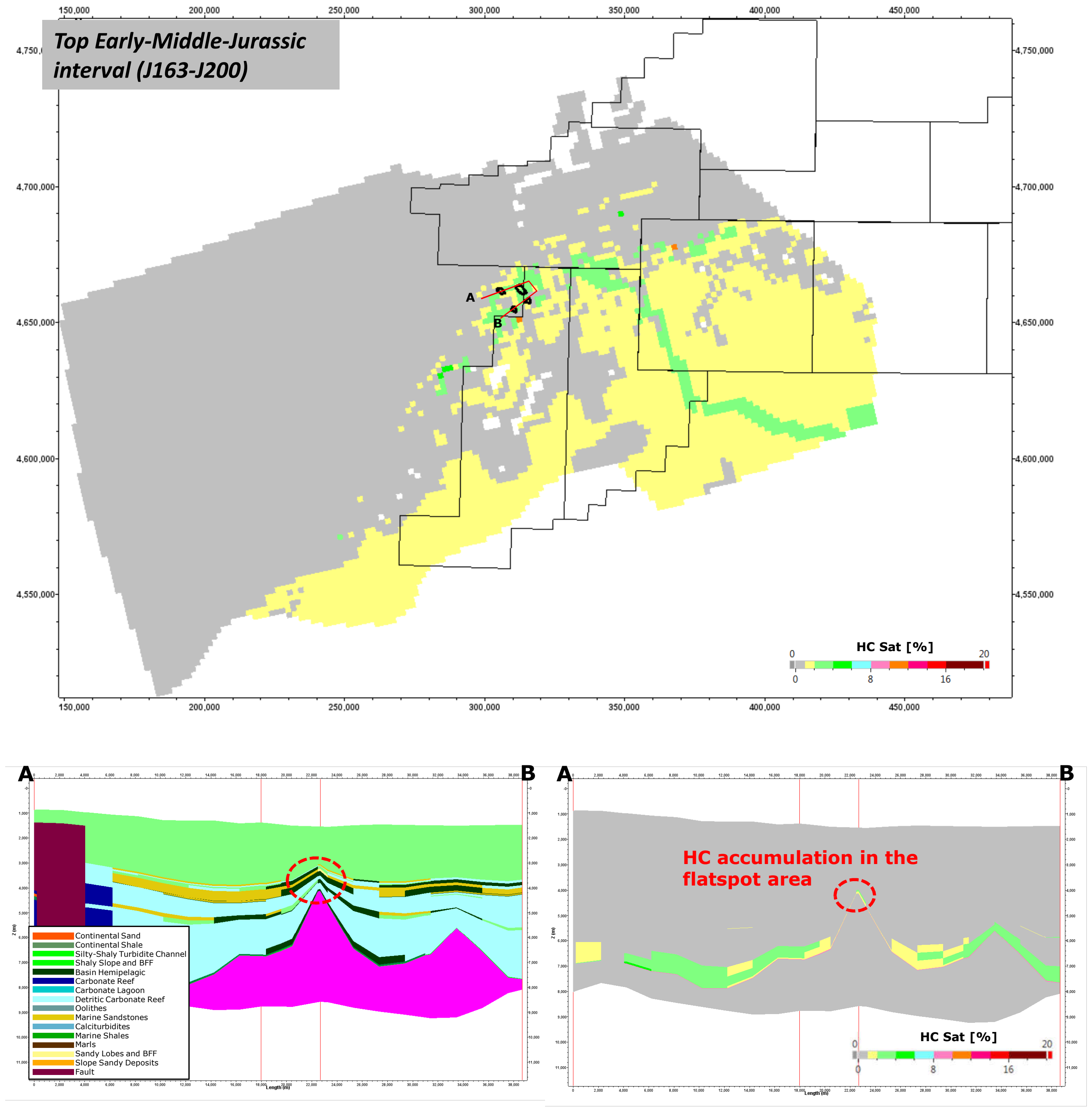


Figure 44: Flatspots evidence in the Top Early-Middle Jurassic interval and results of the simulation.

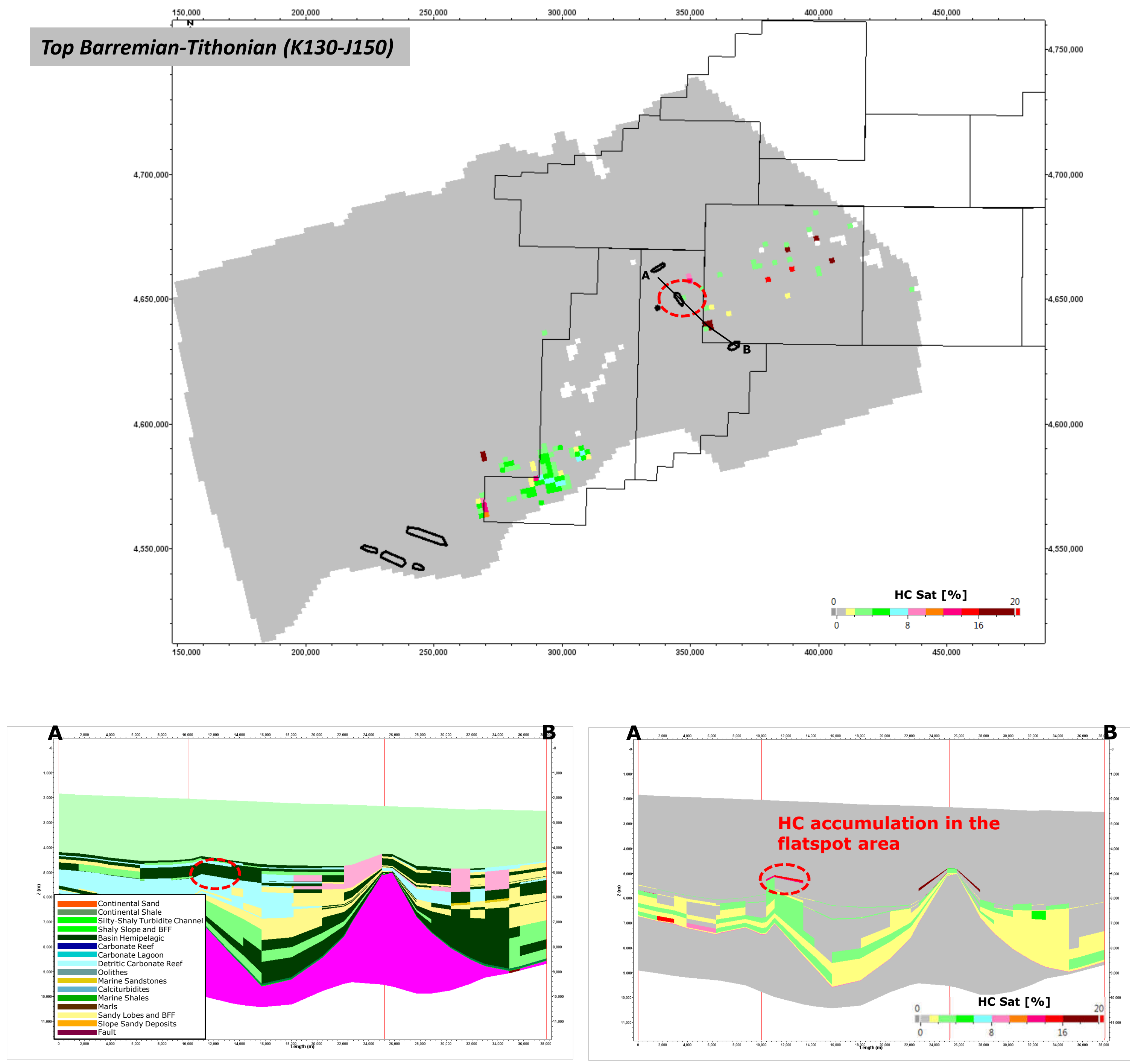


Figure 45: Flatspots evidence in the Barremian-Tithonian interval and results of the simulation.

Migration Results

The migration model shows several traps related to stratigraphy (carbonate breccia, reef facies, sandy turbidites, ...) and related to salt (near salt diapirs and under salt canopies). Sections from the 3D result illustrates some examples of these traps. API° is between 25-35 with a maximum of 40 in the deepest zones.

Figures 46 and 47 show two sections from results that give some examples of traps and an idea of the API.

Figure 46: Lithologies distribution, HC accumulations and °API of a SW-NE section.

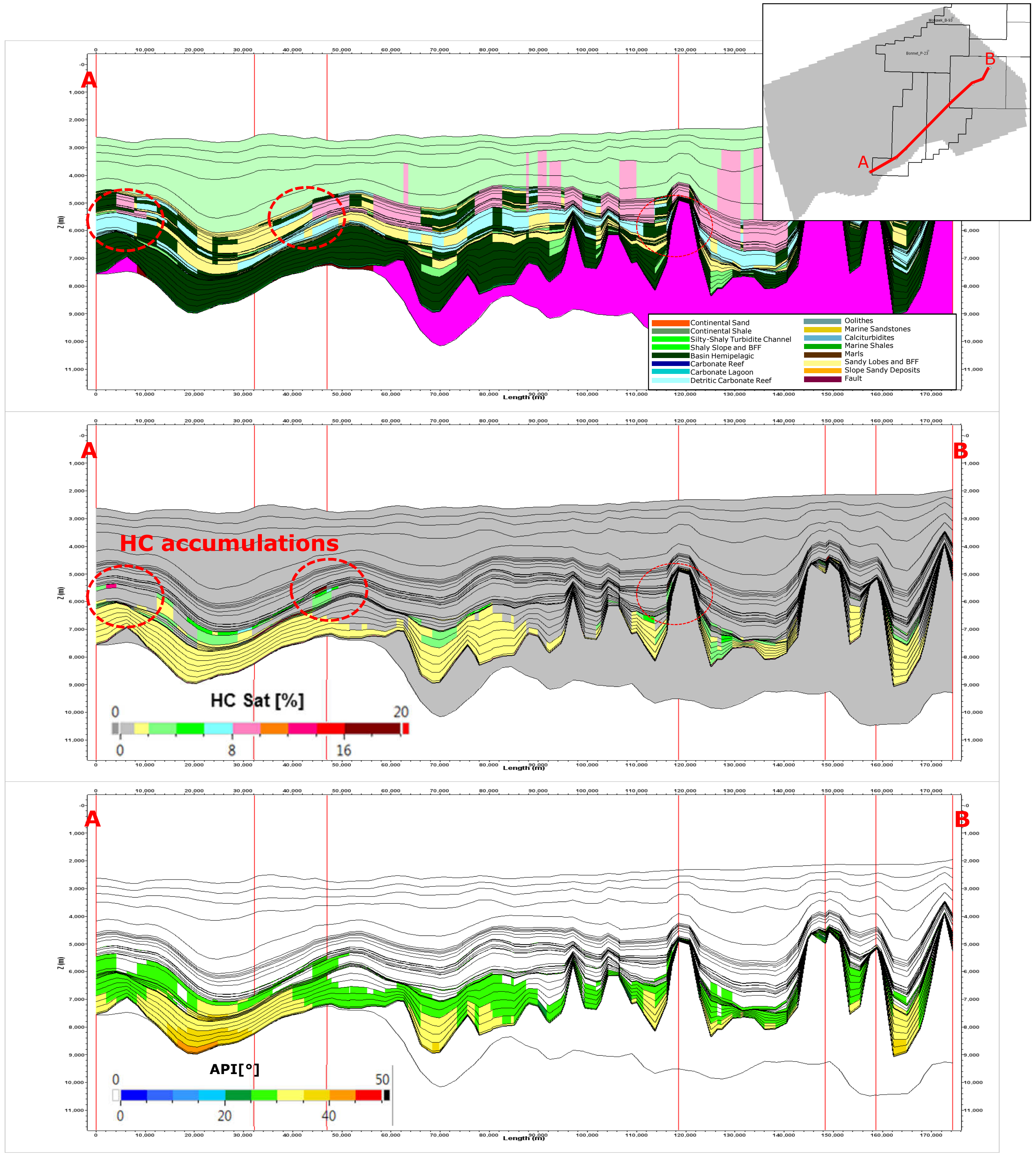
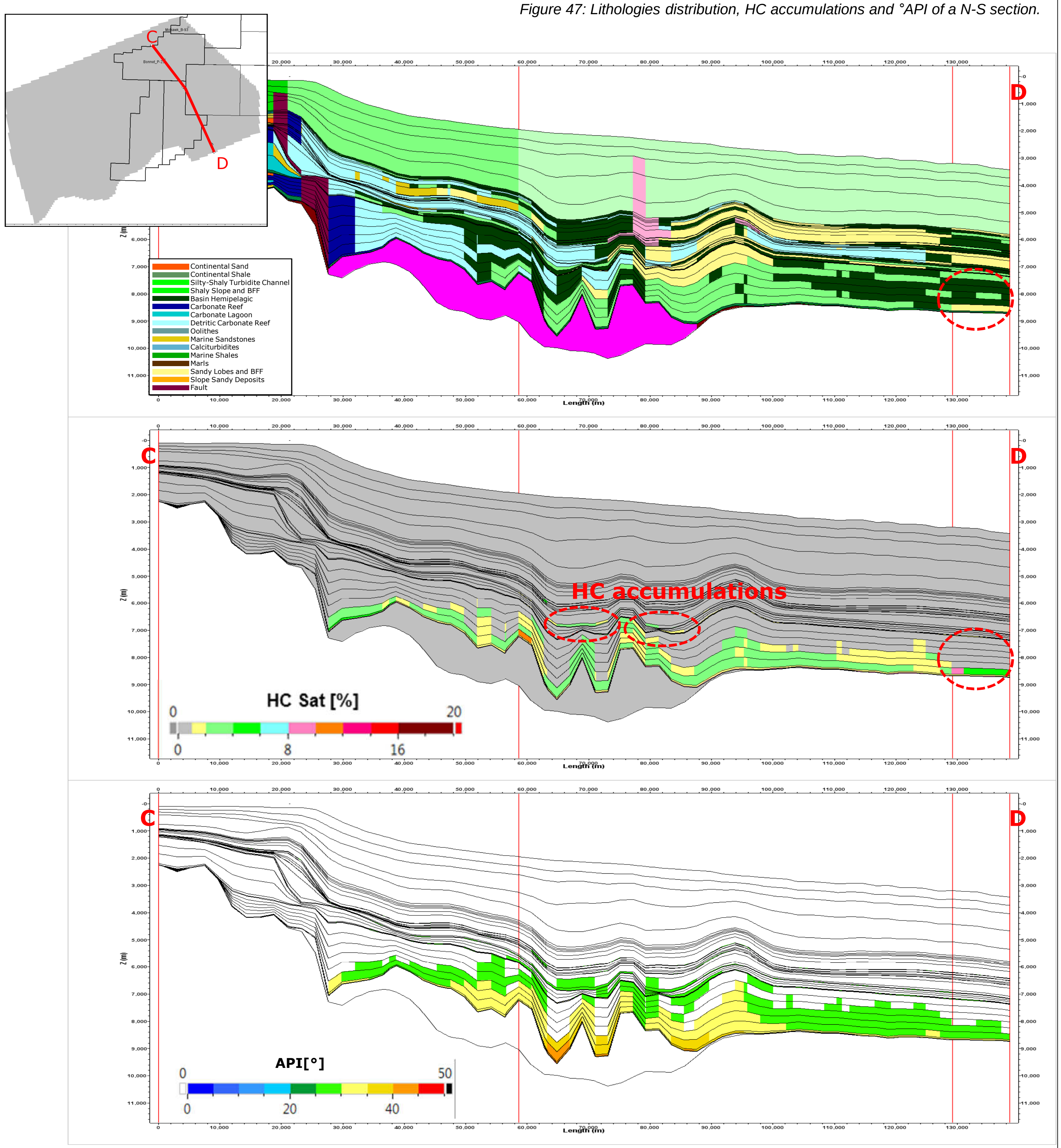


Figure 47: Lithologies distribution, HC accumulations and °API of a N-S section.



Early-Middle-Jurassic interval (J163-J200)

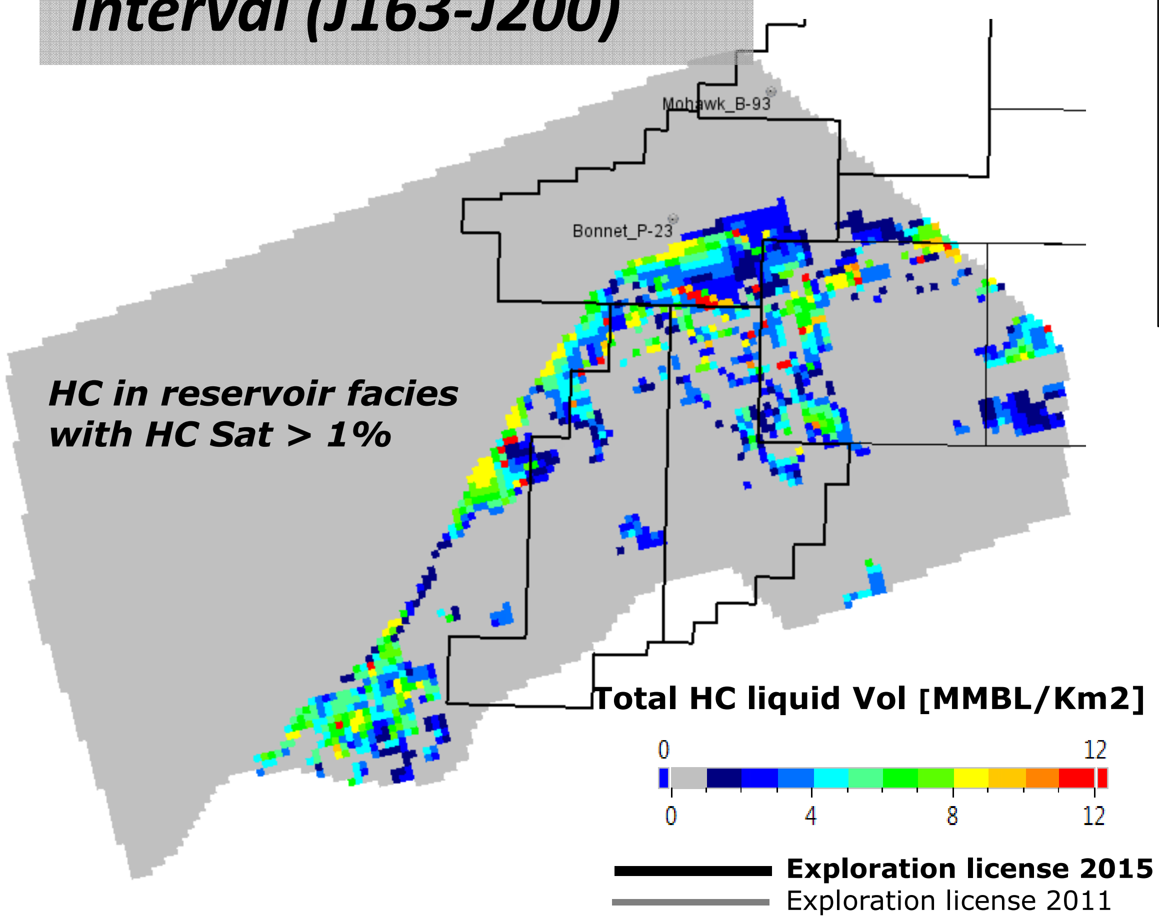


Figure 48: Total HC liquid volume in the Early-Middle Jurassic interval.

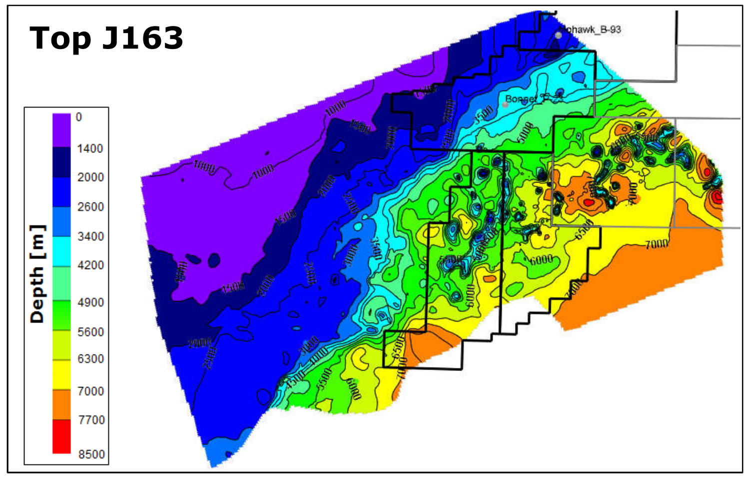


Figure 43: Depth map of J163 (top of Early-Middle Jurassic interval).

Early-Middle Jurassic Play:
Location: Base of the slope and depth basin
Reservoir: Carbonate Breccia, Reef facies, Detritic carbonate deposits and Sandy turbidites basinward (Figure 49).
HC Source: Lower Jurassic SR
Trap Style: Tilted block, lateral pinch-out against the slope or salt diapirs.

Early-Middle Jurassic interval shows important accumulations *(up to 23 BBL – see Table 10)* near the slope in facies reservoir (carbonates and sand) (Figures 48 and 49).

A redistribution of HCs trapped on top J163 was done using the *Trap Charge Assessment* tool. TCA redistributes the total HC volume trapped in the interval (in reservoir facies with an HC Sat > 1%) on the top of J163 (Figure 42) using drainage areas.
Thickness, porosity, temperature and pressure are extracted from results and applied in the interval.
TCA result allows to have an idea of the amount and nature of HCs trapped (volume, mass, GOR, OWC, etc…).

Maps and table from TCA (Table 11, Figures 50 and 51) shows mostly oil in reservoirs, with important quantities accumulated in this play (mostly in the slope).

HC Sat Cutoff	Total Volume of Liquid (in place)
>1 %	23 BBL
>5 % ~P10	5.9 BBL
>10 % ~P50	1.3 BBL
>12 % ~P90	0.97 BBL

Table 10: P10, P50, P90 and the total volume of HC accumulated in the Early-Middle Jurassic interval.

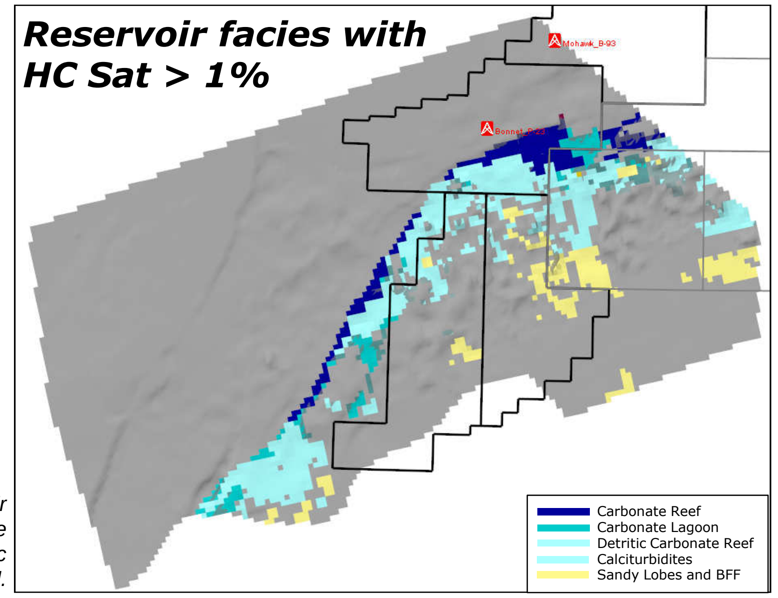


Figure 49: Reservoir facies distribution in the Early-Middle Jurassic interval.

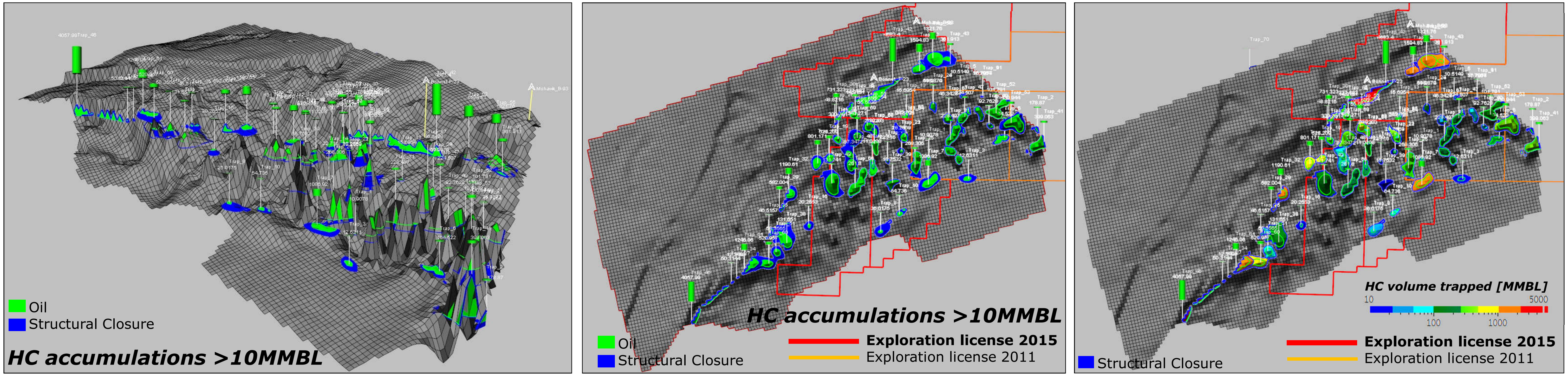


Figure 50: Redistribution of HCs volumes in the Early-Middle Jurassic interval using Trap Charge Assessment tool. HC volumes trapped and traps ranking.

Early-Middle-Jurassic interval (J163-J200)

	Total Liquid Mass [kg]	Total Liquid 1_OIL-Heavy Mass [kg]	Total Liquid 2_OIL-Normal Mass [kg]	Total Liquid 3_OIL-Condensate Mass [kg]	Total Liquid 4_GAS-Thermogenic Mass [kg]	Total Volume of Liquid (in place) [MMstb]	Total Volume of Liquid from Liquid (std) [MMstb]	Mean Temperature [°C]	Mean mass GOR of Liquid Phase [mg/g]	Mean vol, GOR of Liquid Phase [ft³/stb]	Mean mass GOR of Total HC [mg/g]	Mean API Gravity of Liquid from Liquid [°API]
Trap_1	1,33E+09	5,18E+08	5,96E+08	1,26E+08	9,42E+07	10,9078	8,7297	123,353	75,9433	515,1191	75,9433	26,86
Trap_2	1,67E+10	3,98E+09	6,75E+09	1,93E+09	3,98E+09	178,8696	90,8107	121,075	314,5411	2094,3866	314,5411	29,8185
Trap_3	1,58E+09	5,45E+08	7,66E+08	1,86E+08	8,60E+07	12,6311	10,6366	107,77	57,4097	385,8317	57,4097	28,3274
Trap_3	1,58E+09	5,45E+08	7,66E+08	1,86E+08	8,60E+07	12,6311	10,6366	107,77	57,4097	385,8317	57,4097	28,3274
Trap_5	1,01E+09	1,83E+08	4,51E+08	1,94E+08	1,83E+08	10,5149	6,0579	116,772	220,6897	1439,9042	220,6897	33,1312
Trap_6	1,93E+10	6,30E+09	9,09E+09	2,27E+09	1,59E+09	164,5219	125,6637	107,894	90,1591	605,0919	90,1591	28,5487
Trap_7	1,28E+11	3,96E+10	6,13E+10	1,64E+10	1,06E+10	1086,9233	837,2345	105,541	90,3508	604,2244	90,3508	29,1192
Trap_8	2,79E+09	8,21E+08	1,28E+09	3,46E+08	3,46E+08	26,0175	17,4674	96,6397	141,5761	946,3198	141,5761	29,1999
Trap_9	1,95E+09	5,72E+08	9,10E+08	2,57E+08	2,13E+08	17,7954	12,4421	112,08	122,1795	815,4123	122,1795	29,4477
Trap_10	7,90E+09	2,59E+09	3,83E+09	9,72E+08	5,02E+08	64,736	52,6597	95,779	67,8814	455,0761	67,8814	28,7251
Trap_11	2,87E+09	6,13E+08	1,06E+09	3,10E+08	8,94E+08	36,7077	14,1985	110,602	451,893	3005,8763	451,893	29,9835
Trap_13	1,87E+09	5,86E+08	9,21E+08	2,53E+08	1,09E+08	15,6954	12,5753	112,851	62,104	414,8915	62,104	29,2862
Trap_14	2,59E+09	8,03E+08	1,24E+09	3,31E+08	2,20E+08	22,716	16,9127	112,131	92,9659	621,7935	92,9659	29,0984
Trap_16	1,60E+09	4,59E+08	5,59E+08	1,23E+08	4,59E+08	20,2653	8,0589	105,611	402,1268	2720,4809	402,1268	27,2746
Trap_17	7,95E+10	2,08E+10	3,76E+10	1,09E+10	1,02E+10	801,1709	497,7682	106,518	147,9211	982,7085	147,9211	30,1848
Trap_19	5,31E+10	1,43E+10	2,51E+10	7,19E+09	6,50E+09	525,2092	334,3297	102,132	139,531	928,0279	139,531	30,0003
Trap_21	1,93E+09	5,36E+08	8,89E+08	2,51E+08	2,51E+08	18,2669	12,0072	123,965	149,5972	997,0931	149,5972	29,6579
Trap_22	1,86E+09	3,67E+08	8,51E+08	2,75E+08	3,67E+08	20,2363	10,8342	118,212	245,8547	1617,5529	245,8547	31,7615
Trap_23	1,11E+10	2,93E+09	4,78E+09	1,34E+09	2,06E+09	118,3793	64,7886	114,641	227,7878	1519,2524	227,7878	29,5513
Trap_24	5,99E+09	1,60E+09	2,35E+09	6,03E+08	1,43E+09	69,9874	32,4581	116,051	313,4274	2101,3815	313,4274	28,7123
Trap_25	2,93E+10	8,37E+09	1,38E+10	3,84E+09	3,28E+09	268,3063	185,9062	119,153	126,4661	843,3236	126,4661	29,5807
Trap_26	5,17E+09	1,01E+09	2,76E+09	9,21E+08	4,73E+08	48,8216	34,249	104,606	100,7599	659,6179	100,7599	32,5812
Trap_27	5,12E+09	1,47E+09	2,35E+09	6,54E+08	6,46E+08	50,3144	32,0082	98,9097	144,4253	963,8896	144,4253	29,4458
Trap_29	6,05E+10	1,86E+10	2,81E+10	7,28E+09	6,56E+09	582,0043	384,636	98,0008	121,6282	814,4595	121,6282	28,9089
Trap_30	7,54E+10	1,64E+10	3,91E+10	1,27E+10	7,29E+09	731,3226	495,0155	101,207	107,0261	703,5081	107,0261	31,9121
Trap_31	1,95E+10	4,67E+09	7,99E+09	2,31E+09	4,52E+09	228,4969	107,4446	112,305	302,0528	2010,1728	302,0528	29,9036
Trap_32	1,21E+11	3,08E+10	5,88E+10	1,76E+10	1,39E+10	1190,6108	771,8918	101,159	129,47	858,1324	129,47	30,561
Trap_34	1,27E+09	3,64E+08	5,86E+08	1,63E+08	1,53E+08	12,3498	7,9614	97,4008	137,5996	918,2035	137,5996	29,4689
Trap_35	3,26E+09	9,26E+08	1,14E+09	2,60E+08	9,26E+08	46,5157	16,461	88,8995	397,5377	2686,9073	397,5377	27,4239
Trap_36	1,67E+09	5,36E+08	7,91E+08	2,04E+08	1,38E+08	14,977	10,903	109,697	90,0618	603,6454	90,0618	28,759
Trap_37	3,18E+10	7,70E+09	1,51E+10	4,59E+09	4,42E+09	330,7811	197,2023	104,31	161,5955	1069,7826	161,5955	30,7547
Trap_38	1,18E+10	3,50E+09	4,99E+09	1,23E+09	2,10E+09	131,6514	69,1015	93,6026	216,3006	1452,5783	216,3006	28,4491
Trap_39	1,97E+09	5,89E+08	9,01E+08	2,41E+08	2,41E+08	18,7532	12,3504	99,1634	139,0676	930,3368	139,0676	29,0645
Trap_40	9,42E+09	2,69E+09	4,27E+09	1,20E+09	1,26E+09	92,7628	58,3111	106,313	154,9531	1034,2821	154,9531	29,4255
Trap_41	4,52E+10	1,47E+10	2,07E+10	5,03E+09	4,84E+09	399,0633	286,8104	112	119,8848	805,657	119,8848	28,3371
Trap_42	4,39E+11	1,21E+11	1,99E+11	5,51E+10	6,41E+10	4683,3992	2686,2115	103,587	170,8409	1139,3853	170,8409	29,559
Trap_43	3,07E+10	8,08E+09	1,34E+10	3,65E+09	5,61E+09	361,9132	179,6733	91,7568	223,673	1491,8752	223,673	29,544
Trap_44	1,25E+09	3,84E+08	4,99E+08	1,13E+08	2,54E+08	14,9151	7,0484	107,311	254,9289	1719,9889	254,9289	27,7051
Trap_45	2,85E+10	8,06E+09	1,22E+10	3,21E+09	5,09E+09	337,5829	167,1528	102,67	217,3329	1454,8919	217,3329	28,9569
Trap_46	3,40E+11	8,75E+10	1,36E+11	3,68E+10	7,94E+10	4057,9908	1862,5668	101,606	304,6757	2036,5427	304,6757	29,1971
Trap_47	1,87E+10	4,32E+09	7,36E+09	2,14E+09	4,83E+09	224,5072	99,1571	113,915	349,0871	2323,2487	349,0871	29,8993
Trap_48	7,87E+09	2,36E+09	3,32E+09	7,92E+08	1,40E+09	87,3472	45,9351	102,223	216,4533	1455,1763	216,4533	28,2762
Trap_49	1,28E+10	4,33E+09	5,53E+09	1,22E+09	1,71E+09	131,7407	78,2775	91,3902	154,1731	1041,3102	154,1731	27,5348
Trap_50	8,17E+08	2,18E+08	3,08E+08	7,31E+07	2,18E+08	11,0208	4,2543	87,6395	363,5555	2443,7954	363,5555	28,2973
Trap_51	5,17E+09	1,45E+09	2,18E+09	5,67E+08	9,84E+08	58,3565	29,8723	95,5536	234,917	1573,1584	234,917	28,9005
Trap_52	7,75E+09	1,94E+09	2,86E+09	7,76E+08	2,18E+09	101,7905	39,7396	95,2759	390,1613	2612,782	390,1613	28,9001
Trap_53	3,62E+10	9,36E+09	1,43E+10	3,78E+09	8,82E+09	430,9445	195,6131	100,117	321,715	2152,8158	321,715	29,0196
Trap_54	3,83E+09	1,02E+09	1,26E+09	3,02E+08	1,25E+09	55,6838	18,233	105,325	486,0823	3283,0565	486,0823	27,5359
Trap_55	5,70E+10	1,31E+10	2,22E+10	6,39E+09	1,53E+10	768,6023	299,1626	101,548	366,3199	2438,8304	366,3199	29,8402
Trap_56	1,12E+11	3,02E+10	4,76E+10	1,29E+10	2,14E+10	1321,7597	647,6642	92,7855	235,4999	1573,602	235,4999	29,2531
Trap_57	1,21E+10	3,21E+09	5,33E+09	1,50E+09	2,05E+09	133,3698	71,9556	101,579	203,8159	1358,4761	203,8159	29,6572
Trap_58	1,90E+09	5,20E+08	6,91E+08	1,71E+08	5,20E+08	24,9203	9,7959	105,385	376,5509	2534,9483	376,5509	28,0579
Trap_60	4,43E+10	1,22E+10	1,79E+10	4,50E+09	9,65E+09	520,9567	246,3459	99,6004	278,9294	1870,8246	278,9294	28,6492
Trap_61	1,24E+11	3,58E+10	5,79E+10	1,60E+10	1,45E+10	1246,0555	784,5962	86,356	132,268	882,6383	132,268	29,4666
Trap_62	1,31E+11	3,57E+10	5,55E+10	1,50E+10	2,49E+10	1594,8318	757,8066	95,7367	234,9658	1570,7495	234,9658	29,1799
Trap_64	1,03E+10	2,96E+09	4,95E+09	1,41E+09	1,01E+09	94,5635	66,7357	116,483	108,2154	720,972	108,2154	29,7257
Trap_65	4,40E+10	1,19E+10	2,22E+10	6,69E+09	3,18E+09	385,4063	294,0608	111,258	77,836	516,191	77,836	30,4697
Trap_66	2,50E+10	7,54E+09	1,12E+10	2,90E+09	3,38E+09	261,8002	153,8504	84,5608	156,4036	1048,01	156,4036	28,8042
Trap_67	3,71E+09	8,57E+08	1,46E+09	4,24E+08	9,69E+08	46,3428	19,6762	107,753	353,4529	2352,3456	353,4529	29,8965
Trap_69	2,47E+10	5,74E+09	9,30E+09	2,59E+09	7,03E+09	343,2708	126,2079	98,5024	398,5799	2659,2364	398,5799	29,4986
Trap_70	1,39E+09	4,64E+08	6,04E+08	1,37E+08	1,88E+08	21,3716	9,2526	49,1441	155,9376	1052,1009	254,9291	27,7051
TOTAL	**2,29E+12**	**6,34E+11**	**9,95E+11**	**2,75E+11**	**3,89E+11**	**2,47E+04**	**1,38E+04**					

Table 11: Total HC liquid volume in the Early-Middle Jurassic interval per traps

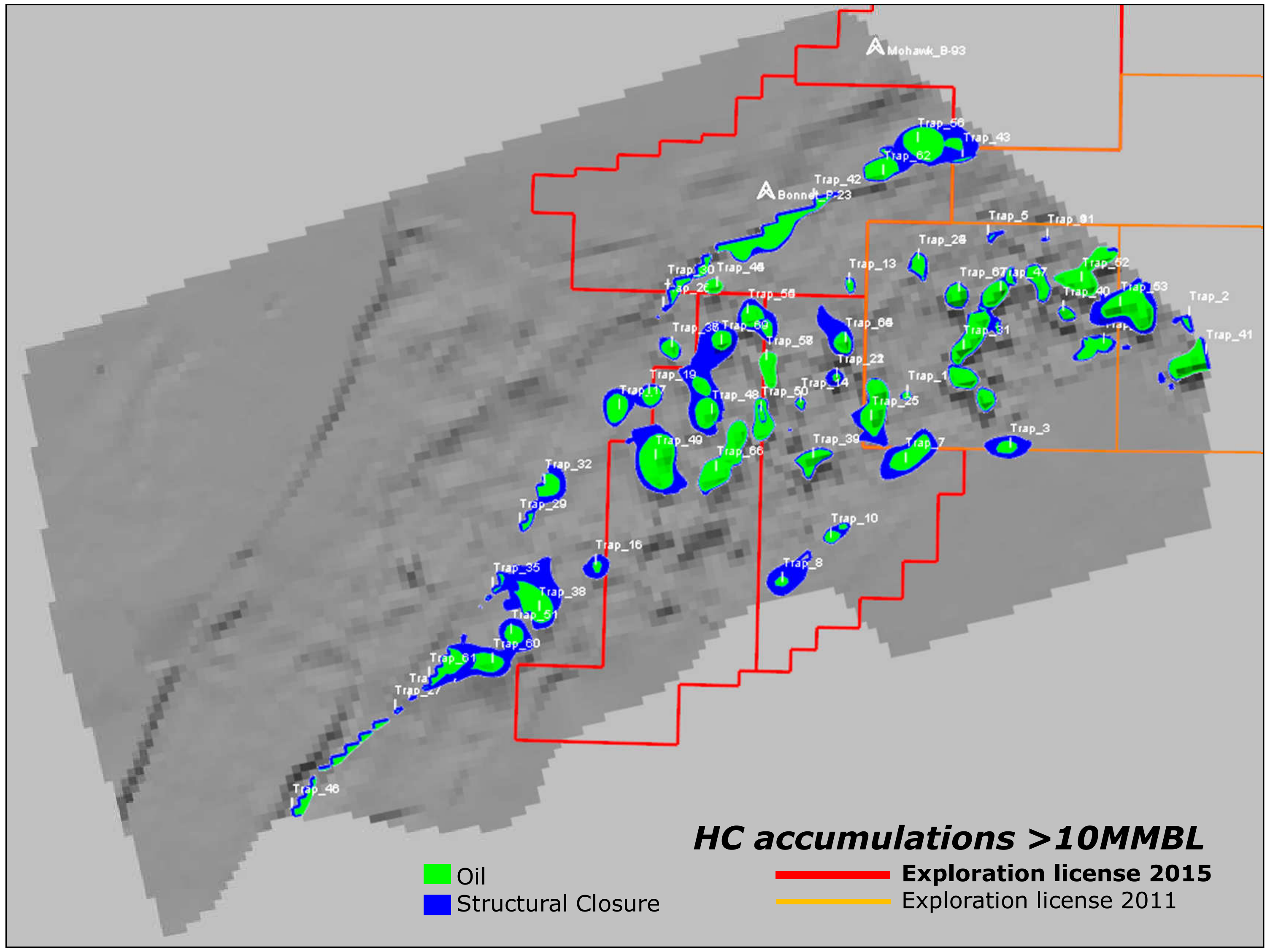


Figure 51: HC traps location in the Early-Middle Jurassic interval – used for Table 11.

Tithonian-Callovian interval (J150-J163)

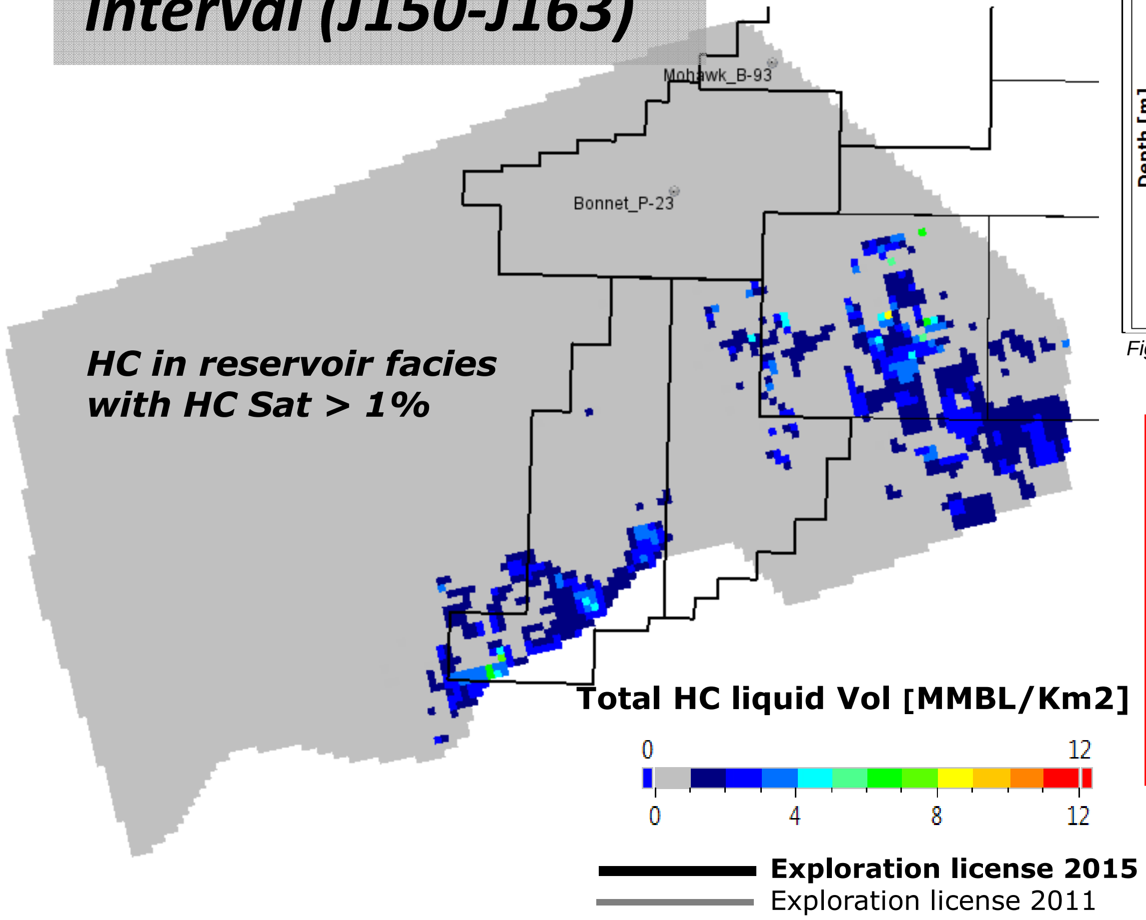


Figure 52: Total HC liquid volume in the Tithonian-Callovian interval.

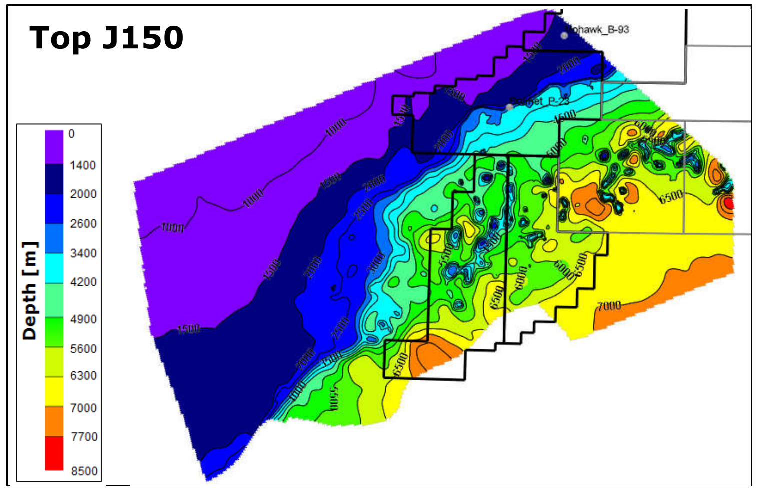


Figure 43: Depth map of J150 (top of Tithonian-Callovian interval).

Upper Jurassic Play:
Location: basin
Reservoir: Calciturbidites, detritic carbonates and Sandy turbidites (Figure 53).
HC Source: Lower Jurassic SR; Callovian SR Locally
Trap Style: lateral pinch-out, stratigraphic traps, pinch-out againts salt diapir flanks; doming structures linked to salt deformation.

Upper Jurassic interval (Figure 43) shows accumulations (Up to *8,2 BBL*) in the basin, mostly located on sandy lobes in the south/south-east of the basin (Table 12, Figures 52 and 53).

A redistribution of HCs trapped on top J150 was done using Trap Charge Assessment tool. TCA redistributes the total HC volume trapped in the interval (in reservoir facies with an HC Sat > 1%) on the top of J150 using drainage areas.
Thickness, porosity, temperature and pressure are extracted from results and applied in the interval.
TCA result allows to have an idea of the amount and nature of HCs trapped (volume, mass, GOR, OWC, etc…).

Maps and table from TCA (Table 13, Figures 53 and 54) shows mostly oil in reservoirs. Drainage areas, mostly created by salt tectonism, tend to redistribute oil in the center of the basin.

HC Sat Cutoff	Total Volume of Liquid (in place)
>1 %	8.2 BBL
>5 % ~P10	5.2 BBL
>10 % ~P50	4 BBL
>12 % ~P90	3.7 BBL

Table 12: P10, P50, P90 and the total volume of HC accumulated in the Tithonian-Callovian interval.

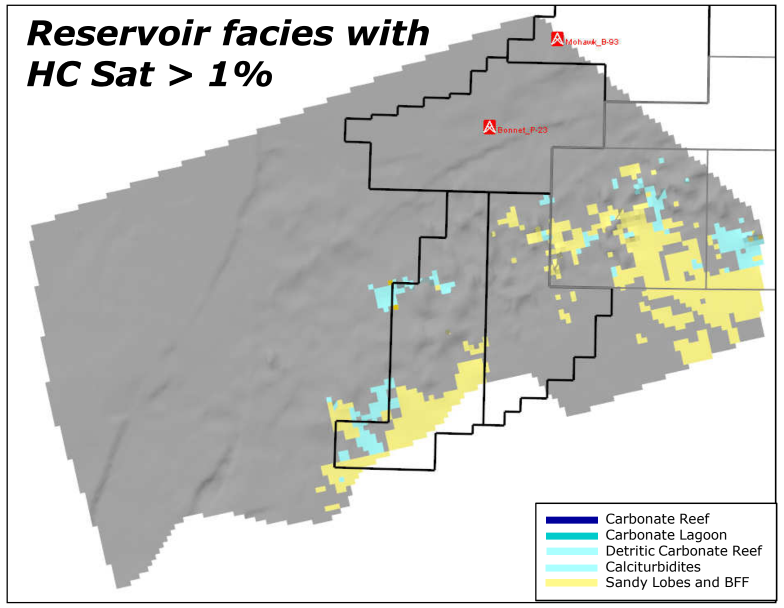


Figure 53: Reservoir facies distribution in the Tithonian-Callovian interval.

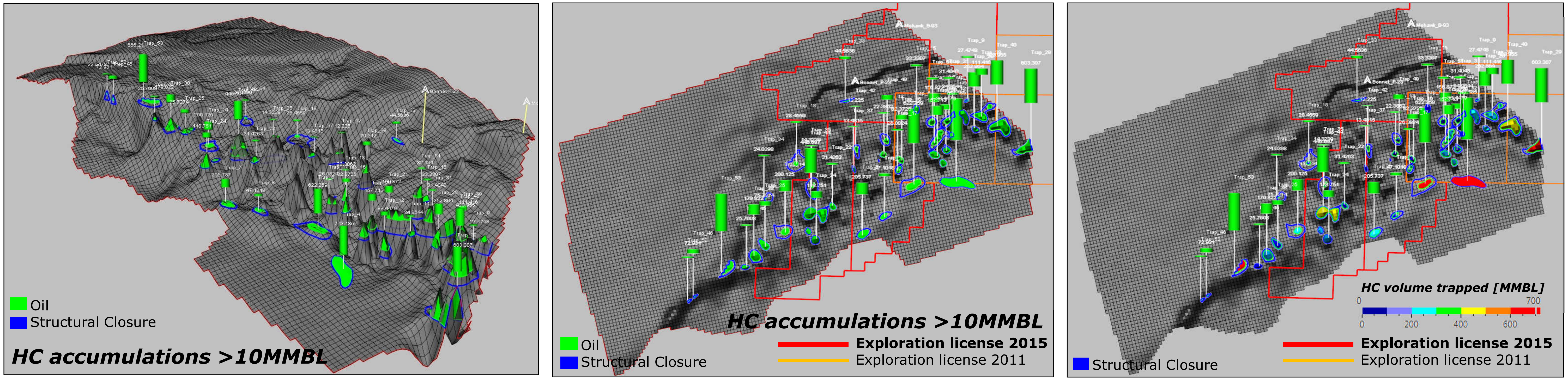


Figure 54: Redistribution of HCs volumes in the Tithonian-Callovian interval using Trap Charge Assessment tool. HC volumes trapped and traps ranking.

Tithonian-Callovian interval (J150-J163)

	Total Liquid Mass [kg]	Total Liquid 1_OIL-Heavy Mass [kg]	Total Liquid 2_OIL-Normal Mass [kg]	Total Liquid 3_OIL-Condensate Mass [kg]	Total Liquid 4_GAS-Thermogenic Mass [kg]	Total Volume of Liquid (in place) [MMstb]	Total Volume of Liquid from Liquid (std) [MMstb]	Mean Temperature [°C]	Mean mass GOR of Liquid Phase [mg/g]	Mean vol, GOR of Liquid Phase [ft³/stb]	Mean mass GOR of Total HC [mg/g]	Mean API Gravity of Liquid from Liquid [°API]
Trap_4	1,05E+11	3,72E+10	5,40E+10	1,31E+10	1,43E+08	743,1851	742,0188	101,016	1,3738	9,222	1,3738	28,5146
Trap_6	8,70E+10	3,07E+10	4,50E+10	1,09E+10	3,41E+08	622,2591	616,1233	99,3843	3,9349	26,4097	3,9349	28,5419
Trap_7	2,91E+10	1,04E+10	1,50E+10	3,69E+09	0	205,7366	206,8031	91,4414	0	0	0	28,4914
Trap_8	6,66E+09	2,33E+09	3,46E+09	8,79E+08	0	47,1018	47,4541	90,3199	0	0	0	28,7647
Trap_9	3,84E+09	1,35E+09	1,99E+09	5,06E+08	0	27,4748	27,3722	104,134	0	0	0	28,7246
Trap_11	4,50E+09	1,45E+09	2,31E+09	6,06E+08	1,35E+08	34,9644	31,1993	109,859	30,9039	206,5468	30,9039	29,2158
Trap_12	1,17E+10	3,86E+09	6,01E+09	1,55E+09	2,56E+08	88,4479	81,5347	114,704	22,4233	150,0167	22,4233	29,0547
Trap_13	3,10E+09	1,02E+09	1,66E+09	4,25E+08	0	22,3862	22,1773	111,1	0	0	0	29,2954
Trap_14	2,72E+10	8,88E+09	1,42E+10	3,95E+09	2,36E+08	200,1248	193,0579	97,4126	8,7361	58,3139	8,7361	29,4194
Trap_15	4,54E+09	1,50E+09	2,41E+09	6,04E+08	3,44E+07	33,3307	32,1762	107,522	7,63	51,0177	7,63	29,1443
Trap_16	1,11E+10	3,55E+09	5,87E+09	1,50E+09	1,52E+08	82,3726	78,056	115,664	13,9344	93,0645	13,9344	29,3303
Trap_17	3,47E+09	1,18E+09	1,78E+09	4,50E+08	6,23E+07	26,0824	24,2663	107,666	18,3015	122,6041	18,3015	28,8413
Trap_18	3,97E+09	1,39E+09	2,14E+09	4,35E+08	0	28,4559	28,1948	99,3304	0	0	0	28,3576
Trap_20	2,07E+10	7,05E+09	1,05E+10	2,56E+09	5,49E+08	157,7132	143,3981	107,466	27,2685	182,8812	27,2685	28,6609
Trap_21	2,04E+10	6,66E+09	1,06E+10	2,75E+09	4,74E+08	156,8716	142,5381	103,849	23,7645	158,8706	23,7645	29,1755
Trap_22	4,42E+09	1,57E+09	2,31E+09	5,47E+08	0	31,4263	31,4371	91,8433	0	0	0	28,5179
Trap_24	1,66E+10	5,40E+09	8,72E+09	2,43E+09	5,68E+06	118,751	118,4279	100,965	0,3429	2,2884	0,3429	29,478
Trap_25	1,01E+10	3,33E+09	5,21E+09	1,39E+09	1,54E+08	75,7274	70,9363	91,2161	15,4604	103,357	15,4604	29,1735
Trap_28	3,45E+10	1,19E+10	1,78E+10	4,52E+09	2,88E+08	252,8636	244,0152	100,363	8,4057	56,3333	8,4057	28,7771
Trap_29	8,48E+10	3,03E+10	4,39E+10	1,05E+10	7,87E+07	603,3073	602,4012	103,161	0,9285	6,2347	0,9285	28,4682
Trap_31	3,91E+09	1,34E+09	1,92E+09	4,85E+08	1,67E+08	31,4043	26,6383	104,652	44,6504	299,6214	44,6504	28,5725
Trap_33	5,83E+09	2,11E+09	2,93E+09	6,86E+08	1,08E+08	44,5636	40,5932	94,5364	18,8449	126,7783	18,8449	28,1656
Trap_34	3,36E+09	1,16E+09	1,85E+09	3,53E+08	0	24,0398	23,8724	95,6508	0	0	0	28,3975
Trap_35	2,00E+09	6,91E+08	1,08E+09	2,25E+08	0	14,3239	14,2112	101,743	0	0	0	28,5011
Trap_37	1,89E+09	6,70E+08	1,02E+09	2,01E+08	0	13,4815	13,4382	84,0298	0	0	0	28,2231
Trap_38	2,47E+10	7,56E+09	1,31E+10	3,87E+09	1,06E+08	179,8219	176,3281	94,3841	4,3239	28,7516	4,3239	30,0383
Trap_39	1,53E+10	5,31E+09	7,89E+09	2,00E+09	9,88E+07	111,4164	108,2791	92,1023	6,4994	43,5621	6,4994	28,762
Trap_40	5,91E+10	2,18E+10	3,02E+10	6,94E+09	2,30E+08	423,9552	417,7113	98,2013	3,9051	26,2836	3,9051	28,0916
Trap_42	1,71E+09	6,16E+08	9,21E+08	1,73E+08	0	12,225	12,1238	96,182	0	0	0	28,0046
Trap_44	6,23E+10	2,05E+10	3,27E+10	9,03E+09	2,02E+07	446,6973	445,4475	89,4106	0,3248	2,1686	0,3248	29,3864
Trap_45	3,44E+09	1,11E+09	1,79E+09	4,92E+08	5,39E+07	25,7608	24,2214	102,553	15,916	106,2168	15,916	29,4545
Trap_46	9,93E+09	3,73E+09	5,02E+09	1,06E+09	1,16E+08	72,931	69,4521	101,042	11,8352	79,8369	11,8352	27,7345
Trap_49	1,07E+10	3,42E+09	5,65E+09	1,51E+09	9,90E+07	79,312	75,7334	106,299	9,3554	62,4308	9,3554	29,4641
Trap_51	4,48E+09	1,55E+09	2,36E+09	5,73E+08	0	32,134	31,9322	99,3388	0	0	0	28,7638
Trap_52	3,18E+09	1,22E+09	1,61E+09	3,47E+08	0	22,5478	22,4928	94,6234	0	0	0	27,6541
Trap_53	8,82E+10	2,84E+10	4,59E+10	1,26E+10	1,37E+09	666,2104	621,3233	78,107	15,7886	105,374	15,7886	29,4436
TOTAL	**8,01E+11**	**2,77E+11**	**4,21E+11**	**9,72E+10**	**5,03E+09**	**5822,3721**	**5669,516**					

Table 13: Total HC liquid volume in the Tithonian-Callovian interval per traps

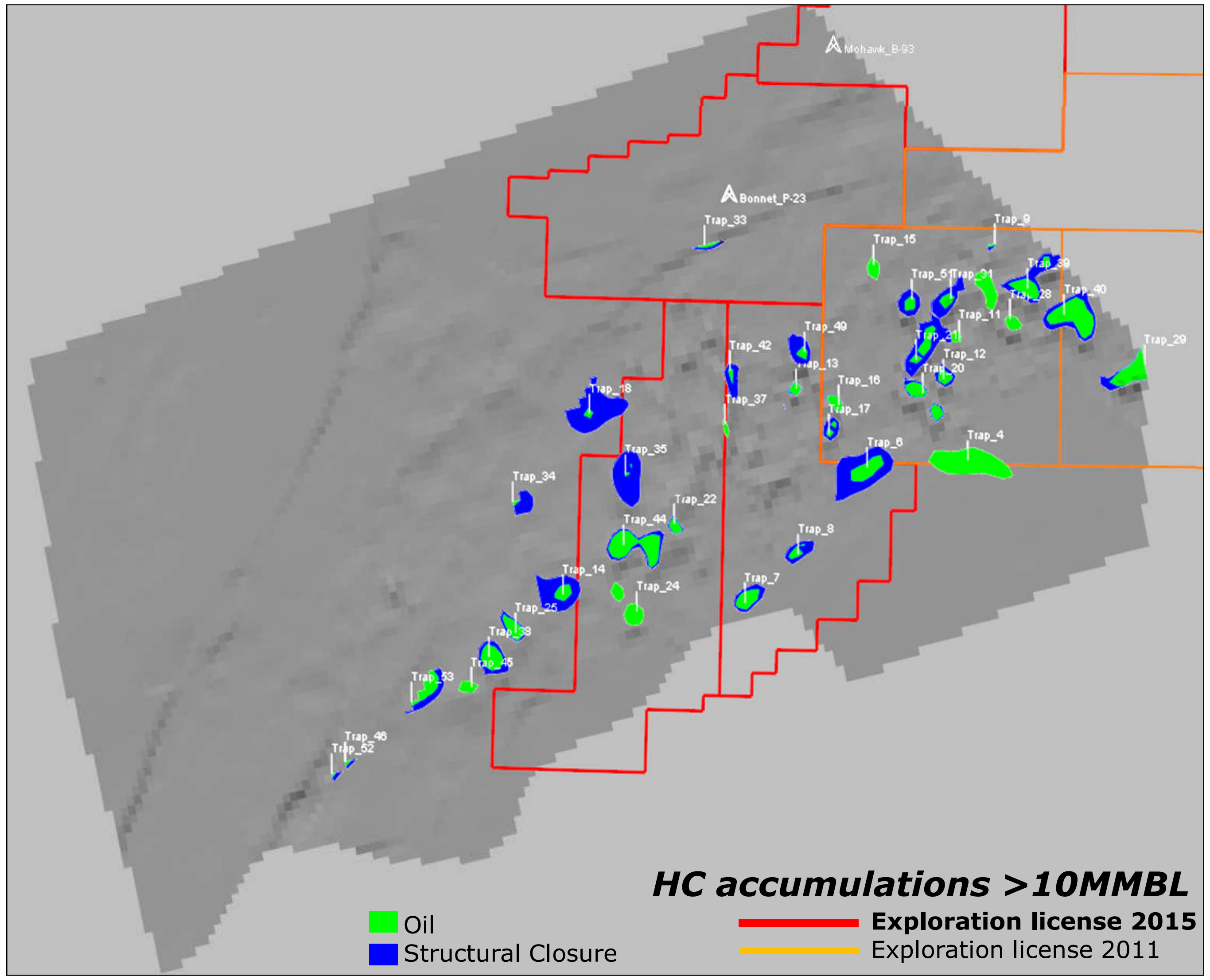


Figure 54: HC traps location in the Tithonian-Callovian interval – used for Table 13.

Barremian-Tithonian interval (K130-J150)

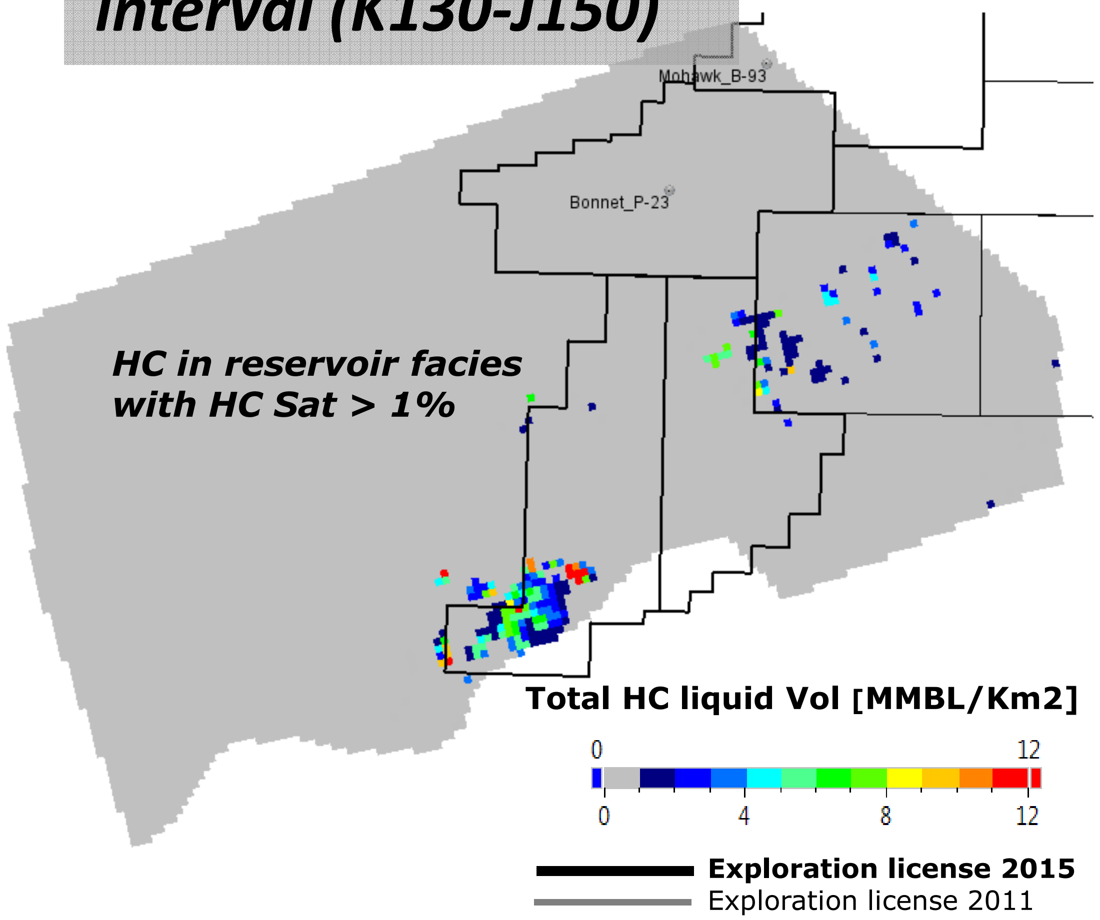


Figure 56: Total HC liquid volume in the Barremian-Tithonian interval.

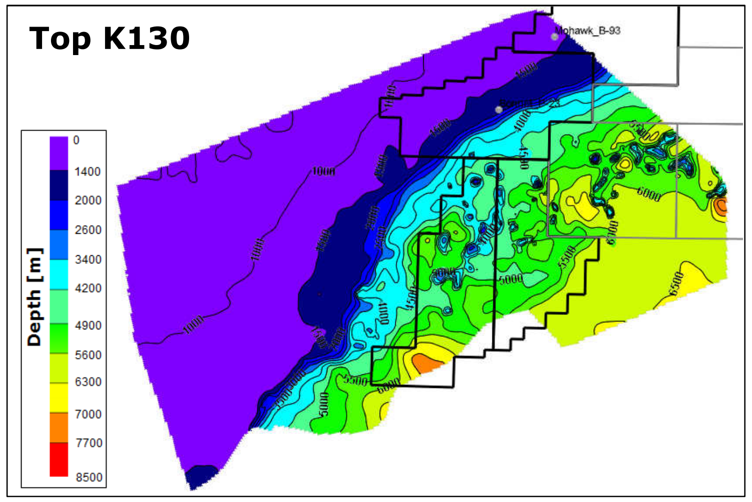


Figure 43: Depth map of K130 (top of Barremian-Tithonian interval).

Upper Jurassic / Lower cretaceous Play:
Location: basin
Reservoir: Calciturbidites, detritic carbonates and Sandy turbidites (Figure 57).
HC Source: Lower Jurassic SR; Callovan and Tithonian SR locally
Trap Style: lateral pinch-out against salt diapir flanks; stratigraphic traps, Top of salt diapirs.

Upper Jurassic/lower Cretaceous interval (Figure 43) shows less important accumulations (*up to 5BBL*) in the basin, mostly located on top salt diapirs (Table 14, Figures 56 and 57).

A redistribution of HCs trapped on top K130 was done using Trap Charge Assessment tool. TCA redistributes the total HC volume trapped in the interval (in reservoir facies with an HC Sat > 1%) on the top of K130 using drainage areas.
Thickness, porosity, temperature and pressure are extracted from results and applied in the interval.
TCA result allows to have an idea of the amount and nature of HCs trapped (volume, mass, GOR, OWC, etc…).

Maps and table from TCA shows (Table 15, Figures 58 and 59) mostly oil in reservoirs. Drainage areas ,mostly created by salt tectonism, tend to redistribute oil accumulated in the south to the center of the basin.

HC Sat Cutoff	Total Volume of Liquid (in place)
>1 %	5 BBL
>5 % ~P10	1.4 BBL
>10 % ~P50	0.9 BBL
>12 % ~P90	0.7 BBL

Table 14: P10, P50, P90 and the total volume of HC accumulated in the Barremian-Tithonian interval.

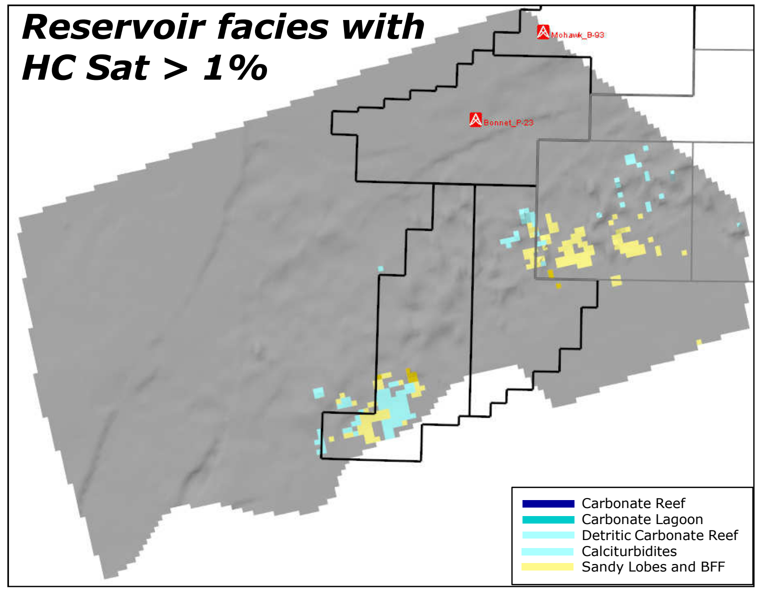


Figure 57: Reservoir facies distribution in the Barremian-Tithonian interval.

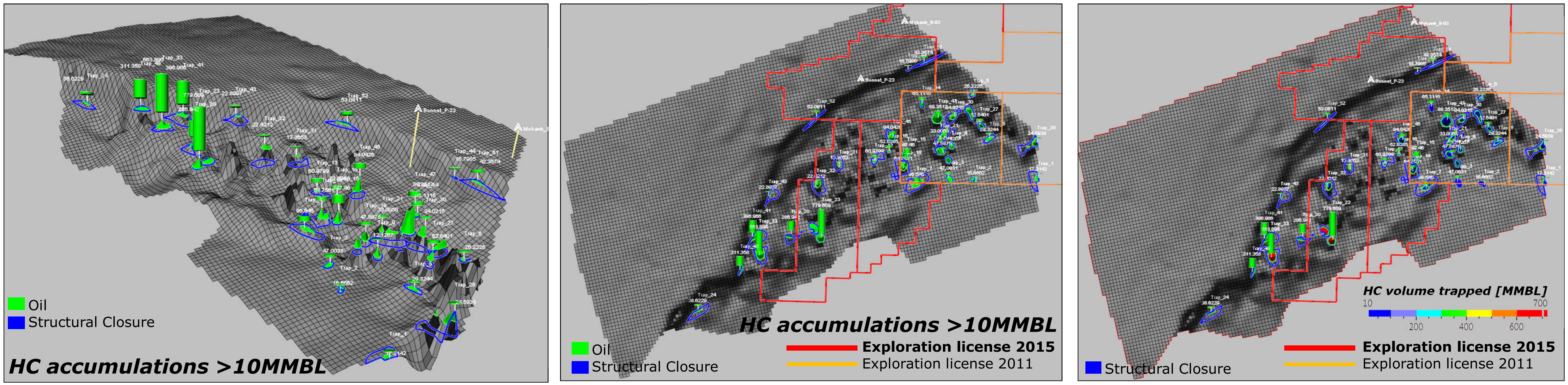


Figure 58: Redistribution of HCs volumes in the Barremian-Tithonian interval using Trap Charge Assessment tool. HC volumes trapped and traps ranking.

Barremian-Tithonian interval (K130-J150)

	Total Liquid Mass [kg]	Total Liquid 1_OIL-Heavy Mass [kg]	Total Liquid 2_OIL-Normal Mass [kg]	Total Liquid 3_OIL-Condensate Mass [kg]	Total Liquid 4_GAS-Thermogenic Mass [kg]	Total Volume of Liquid (in place) [MMstb]	Total Volume of Liquid from Liquid (std) [MMstb]	Mean Temperature [°C]	Mean mass GOR of Liquid Phase [mg/g]	Mean vol, GOR of Liquid Phase [ft³/stb]	Mean mass GOR of Total HC [mg/g]	Mean API Gravity of Liquid from Liquid [°API]
Trap_1	2,18E+09	8,30E+08	1,09E+09	1,44E+08	1,10E+08	17,3142	14,5413	91,9974	53,1013	360,703	53,1013	26,6318
Trap_2	2,09E+09	8,01E+08	1,05E+09	1,37E+08	1,06E+08	16,6662	13,9641	93,3432	53,0916	360,7459	53,0916	26,5841
Trap_3	5,88E+09	2,18E+09	2,93E+09	4,67E+08	3,03E+08	47,0031	39,3167	87,8525	54,3204	367,9582	54,3204	27,0726
Trap_5	3,64E+09	1,36E+09	1,80E+09	2,87E+08	1,87E+08	29,3244	24,3251	96,2984	54,1584	367,0045	54,1584	27,0104
Trap_6	3,30E+09	1,14E+09	1,65E+09	3,73E+08	1,31E+08	26,2226	22,5153	97,9699	41,232	277,1952	41,232	28,2765
Trap_7	1,17E+10	3,81E+09	6,04E+09	1,24E+09	6,09E+08	95,546	78,8675	90,4216	54,8838	368,4036	54,8838	28,5236
Trap_9	1,49E+09	4,76E+08	7,82E+08	1,53E+08	7,59E+07	12,1267	10,0421	103,421	53,7727	360,7624	53,7727	28,6048
Trap_13	8,31E+09	2,88E+09	4,30E+09	1,06E+09	6,94E+07	60,9799	58,7079	89,4394	8,4215	56,462	8,4215	28,7118
Trap_14	8,07E+09	2,70E+09	4,16E+09	8,73E+08	3,47E+08	65,1115	54,9381	98,2124	44,8976	301,5337	44,8976	28,4376
Trap_15	1,86E+10	5,96E+09	9,65E+09	2,34E+09	6,96E+08	147,4596	128,0945	102,536	38,7754	259,3775	38,7754	29,0786
Trap_16	7,07E+09	2,30E+09	3,73E+09	9,70E+08	7,93E+07	52,6365	49,9876	97,6584	11,3331	75,7027	11,3331	29,3055
Trap_18	8,11E+09	2,81E+09	4,03E+09	9,55E+08	3,21E+08	64,7561	55,3568	95,7996	41,1629	276,5597	41,1629	28,375
Trap_19	5,88E+09	1,98E+09	3,02E+09	5,71E+08	3,04E+08	47,8875	39,5768	98,454	54,4072	366,1212	54,4072	28,1229
Trap_20	3,76E+10	1,27E+10	1,92E+10	4,83E+09	8,39E+08	286,9424	261,7684	87,7982	22,8419	153,0311	22,8419	28,8305
Trap_21	4,16E+09	1,46E+09	2,08E+09	4,79E+08	1,46E+08	33,0058	28,5166	97,0966	36,3522	244,4169	36,3522	28,258
Trap_23	1,03E+11	3,35E+10	5,34E+10	1,41E+10	1,87E+09	779,6094	721,5842	92,334	18,5237	123,772	18,5237	29,2564
Trap_24	4,44E+09	1,67E+09	2,24E+09	3,09E+08	2,24E+08	36,6229	29,6862	84,5552	53,1466	360,5793	53,1466	26,8208
Trap_27	6,90E+09	2,45E+09	3,51E+09	7,81E+08	1,62E+08	52,6401	47,8351	94,2567	23,9928	161,3845	23,9928	28,1917
Trap_28	3,06E+09	1,04E+09	1,58E+09	2,89E+08	1,51E+08	24,5939	20,6269	94,995	51,816	348,8987	51,816	28,0249
Trap_30	4,33E+09	1,45E+09	2,18E+09	5,68E+08	1,37E+08	34,0215	29,8964	97,3845	32,622	218,454	32,622	28,9034
Trap_31	1,58E+09	5,08E+08	8,31E+08	1,63E+08	8,07E+07	13,3653	10,6829	90,1737	53,7592	360,726	53,7592	28,5806
Trap_32	2,69E+09	8,96E+08	1,40E+09	2,58E+08	1,37E+08	22,4212	18,1513	95,1371	53,6767	361,0202	53,6767	28,2049
Trap_33	8,82E+10	2,77E+10	4,65E+10	1,26E+10	1,41E+09	663,8958	621,8798	88,9497	16,2265	108,1829	16,2265	29,6126
Trap_41	5,38E+10	1,75E+10	2,84E+10	7,50E+09	4,40E+08	396,9657	381,829	79,9684	8,2425	55,0439	8,2425	29,3479
Trap_43	2,69E+09	9,20E+08	1,39E+09	2,41E+08	1,37E+08	22,8987	18,1044	80,4574	53,4695	360,3203	53,4695	27,8973
Trap_44	2,23E+09	7,46E+08	1,15E+09	2,42E+08	9,60E+07	18,7985	15,1954	82,7745	44,8976	301,5337	44,8976	28,4376
Trap_45	1,02E+10	3,18E+09	5,22E+09	1,28E+09	4,71E+08	84,0426	69,1144	96,8922	48,7152	325,6653	48,7152	29,1779
Trap_47	1,15E+10	3,88E+09	5,85E+09	1,47E+09	3,04E+08	89,3512	79,7975	93,2824	27,1412	181,8653	27,1412	28,8033
Trap_48	4,11E+10	1,45E+10	2,10E+10	4,82E+09	8,11E+08	311,3576	286,346	83,7149	20,1183	135,1892	20,1183	28,3499
Trap_51	5,03E+09	1,72E+09	2,56E+09	4,99E+08	2,49E+08	42,3574	33,9237	82,3769	52,0729	350,505	52,0729	28,0809
Trap_52	6,26E+09	2,19E+09	3,17E+09	6,46E+08	2,47E+08	53,0811	42,6284	77,5086	41,0987	276,7278	41,0987	28,0286
TOTAL	**4,85E+11**	**1,69E+11**	**2,48E+11**	**4,88E+10**	**2,02E+10**	**3733,5134**	**3376,7077**					

Table 15: Total HC liquid volume in the Barremian-Tithonian interval per traps

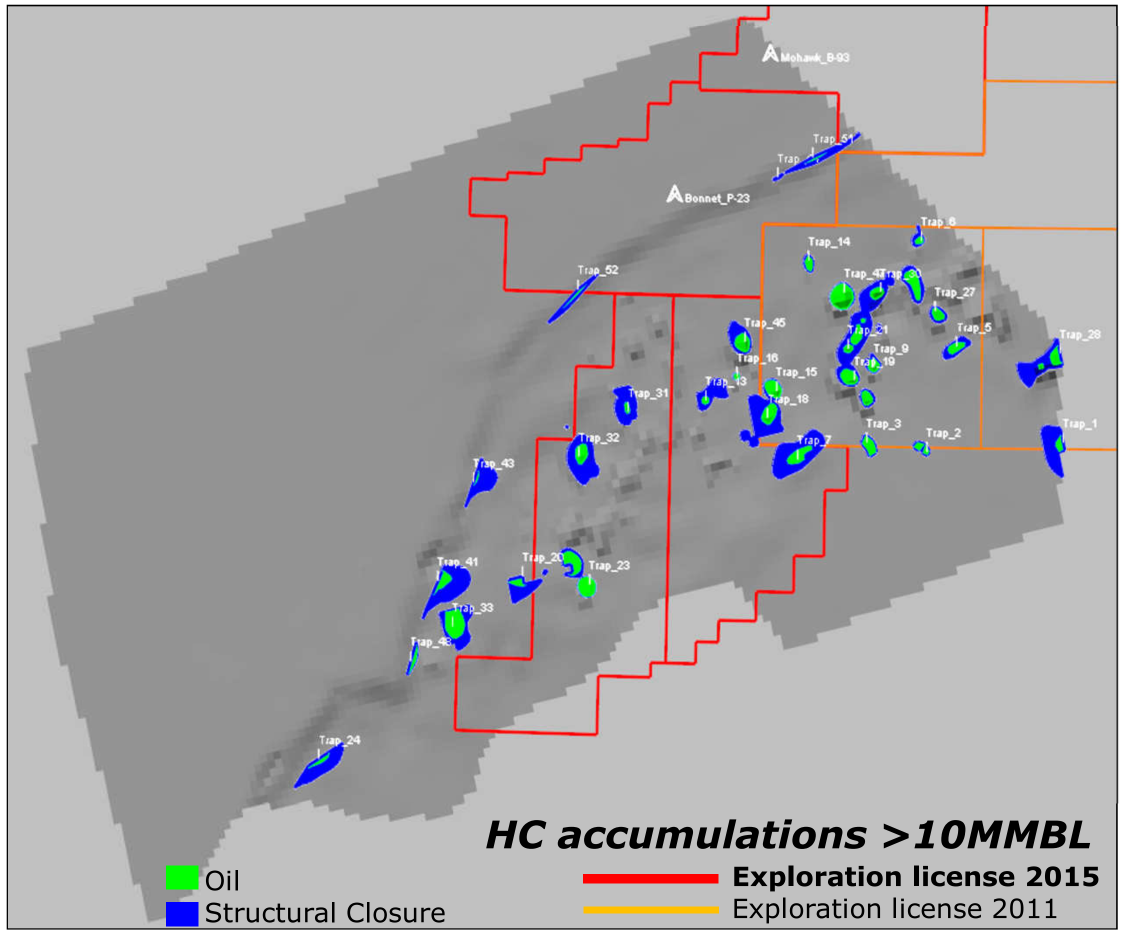


Figure 59: HC traps location in the Barremian-Tithonian interval – used for Table 15.

Albian-Barremian interval (K101-J130)

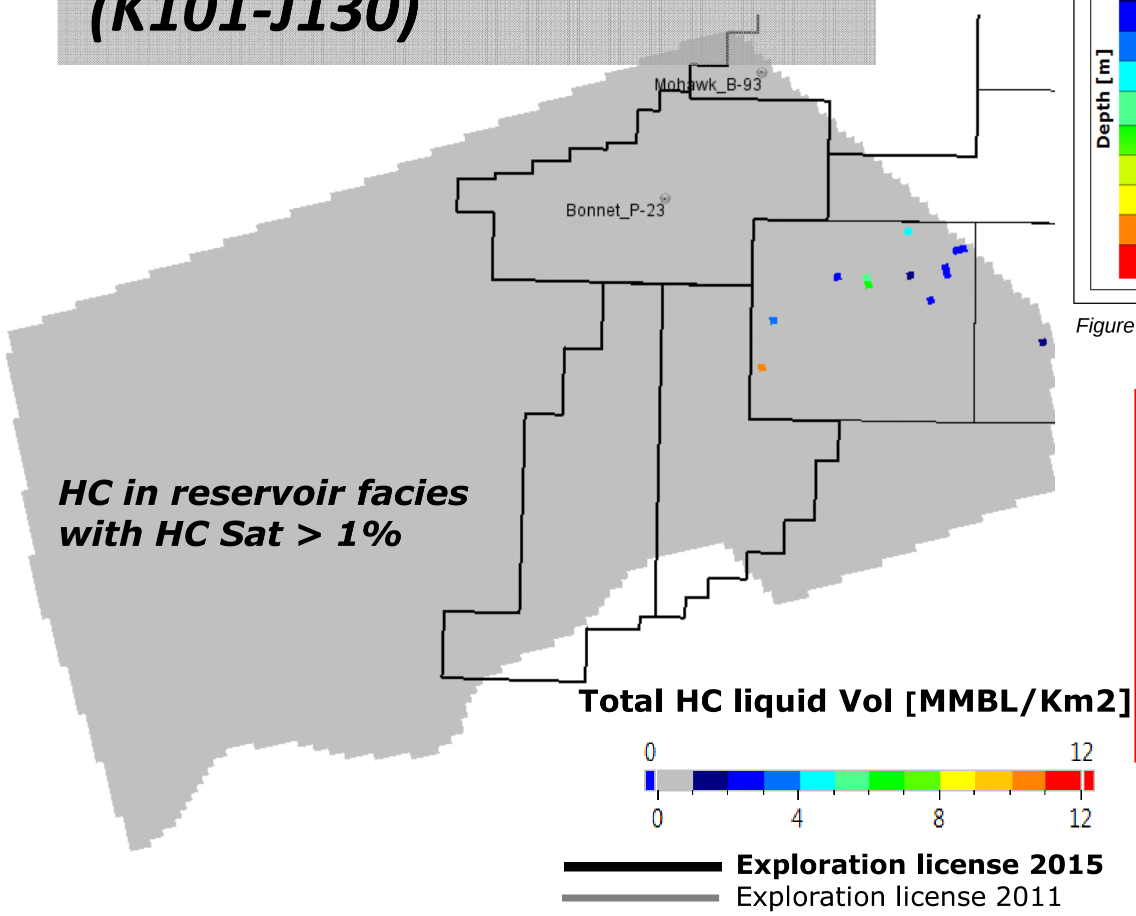


Figure 60: Total HC liquid volume in the Albian-Barremian interval.

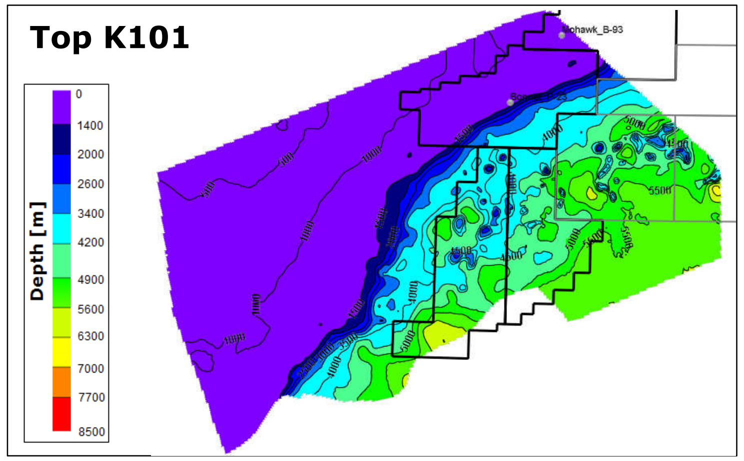


Figure 43: Depth map of K101 (top of Albian-Barremian interval).

Lower cretaceous Play:
Location: basin
Reservoir: Calciturbidites, and Sandy turbidites.
HC Source: Lower Jurassic SR; Callovian and Tithonian SR locally
Trap Style: Top of salt diapirs.

Lower Cretaceous interval (Figure 43) shows few accumulations (0,2BBL) in the east of the basin, mostly located on top salt diapirs (Table 16, Figures 60 and 61).

A redistribution of HCs trapped on top K101 was done using Trap Charge Assessment tool. TCA redistributes the total HC volume trapped in the interval (in reservoir facies with an HC Sat > 1%) on the top of K101 using drainage areas.
Thickness, porosity, temperature and pressure are extracted from results and applied in the interval.
TCA result allows to have an idea of the amount and nature of HCs trapped (volume, mass, GOR, OWC, etc…).

Maps and table from TCA shows (Table 17, Figures 62 and 63) few accumulations, mostly oil in reservoirs located on top salt diapirs.

HC Sat Cutoff	Total Volume of Liquid (in place)
>1 %	0.2 BBL
>5 % ~P10	0.15 BBL
>10 % ~P50	0.10 BBL
>12 % ~P90	0.1 BBL

Table 16: P10, P50, P90 and the total volume of HC accumulated in the Barremian-Tithonian interval.

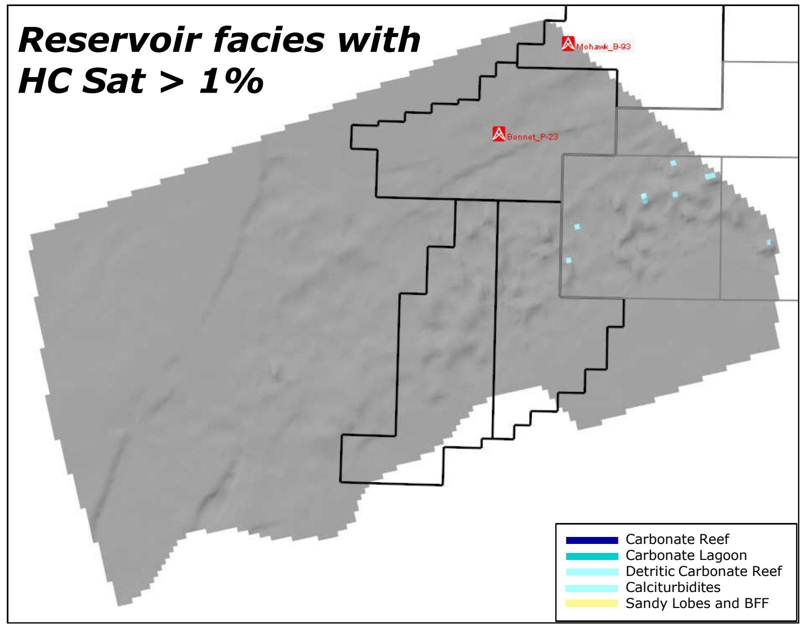


Figure 61: Reservoir facies distribution in the Albian-Barremian interval.

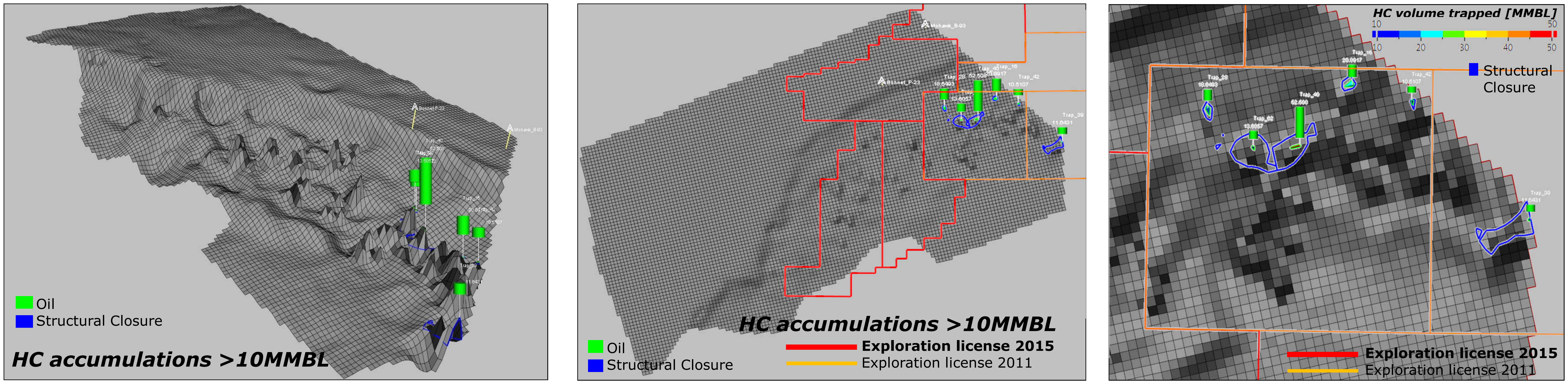


Figure 62: Redistribution of HCs volumes in the Albian-Barremian interval using Trap Charge Assessment tool. HC volumes trapped and traps ranking.

Albian-Barremian interval (K101-J130)

	Total Liquid Mass [kg]	Total Liquid 1_OIL-Heavy Mass [kg]	Total Liquid 2_OIL-Normal Mass [kg]	Total Liquid 3_OIL-Condensate Mass [kg]	Total Liquid 4_GAS-Thermogenic Mass [kg]	Total Volume of Liquid (in place) [MMstb]	Total Volume of Vapor (in place) [MMstb]	Total Volume of Liquid from Liquid (std) [MMstb]	Mean Temperature [°C]	Mean mass GOR of Liquid Phase [mg/g]	Mean vol, GOR of Liquid Phase [ft³/stb]	Mean mass GOR of Total HC [mg/g]	Mean API Gravity of Liquid from Liquid [°API]
Trap_16	2,49E+09	8,68E+08	1,20E+09	2,89E+08	1,36E+08	20,8917	0	16,7032	83,7684	57,6469	387,7299	57,6469	28,2021
Trap_28	2,19E+09	7,54E+08	1,06E+09	2,58E+08	1,22E+08	18,6493	0	14,7227	86,0815	58,8711	395,6345	58,8711	28,335
Trap_39	1,41E+09	4,64E+08	6,98E+08	1,67E+08	7,66E+07	11,6431	0	9,4606	80,7166	57,6489	386,6322	57,6489	28,6609
Trap_40	6,15E+09	2,04E+09	2,99E+09	7,86E+08	3,45E+08	52,508	0	41,3849	84,438	59,4655	398,4991	59,4655	28,7881
Trap_42	1,23E+09	4,06E+08	5,98E+08	1,57E+08	6,93E+07	10,5107	0	8,2782	76,639	59,6899	399,9583	59,6899	28,806
Trap_62	1,59E+09	5,66E+08	7,58E+08	1,83E+08	8,71E+07	13,6057	0	10,6843	80,4742	57,825	389,3068	57,825	28,0467
TOTAL	**1,60E+10**	**5,18E+09**	**7,71E+09**	**1,95E+09**	**1,21E+09**	**136,35**	**1,65E-05**	**107,6085**					

Table 17: Total HC liquid volume in the Albian-Barremian interval per traps

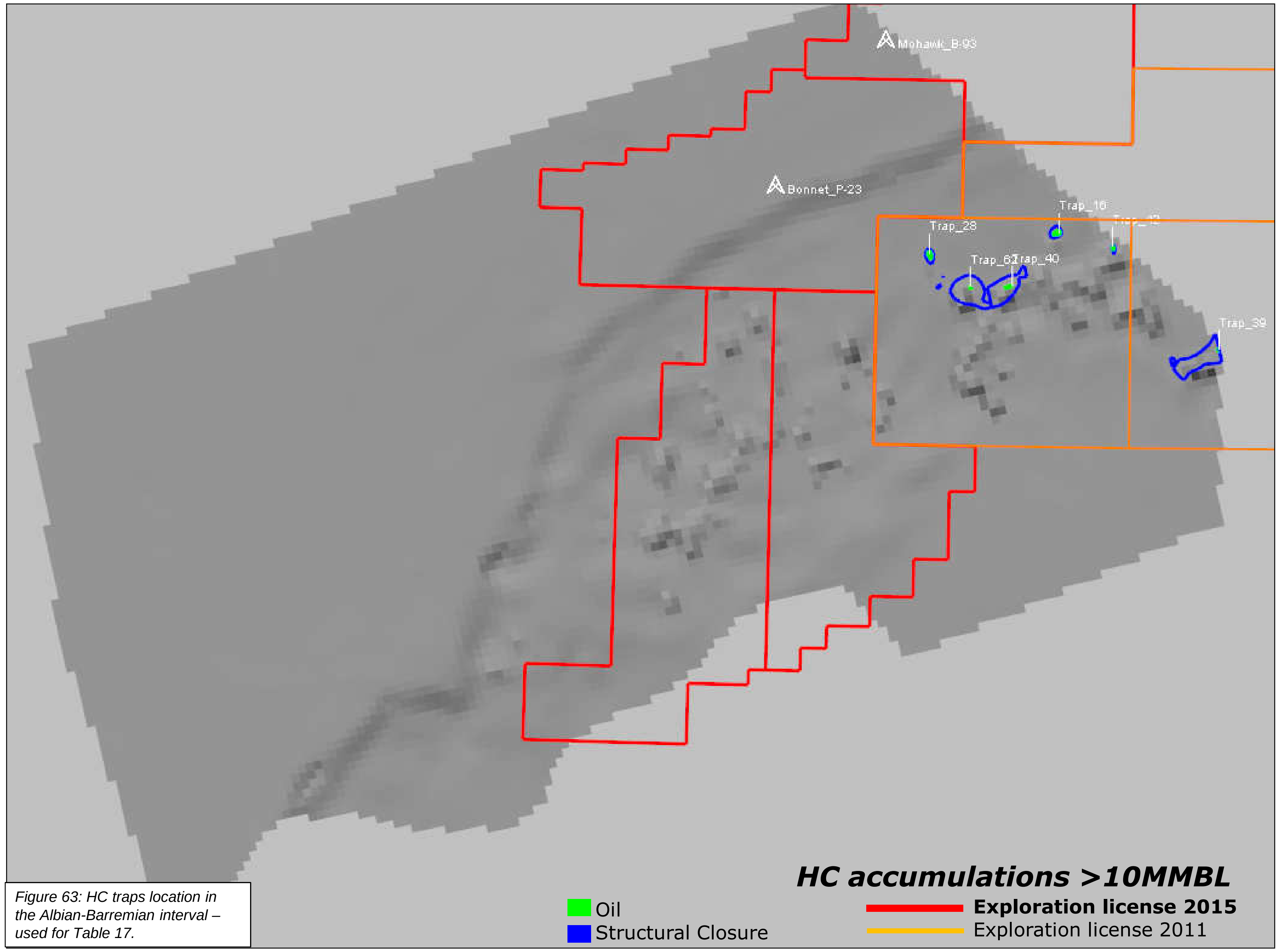


Figure 63: HC traps location in the Albian-Barremian interval – used for Table 17.

Migration discussion

HC quantities that reach the Albian-Barremian interval is clearly limited. Th HC pathway is influenced only by geometry, facies distribution and seal quality. Other scenarios can be explored.
For example the presence of faults (Figure 64) near the depression (graben) in the south area can be possible. Its influence on vertical migration can lead to higher quantities of HCs in the upper intervals.

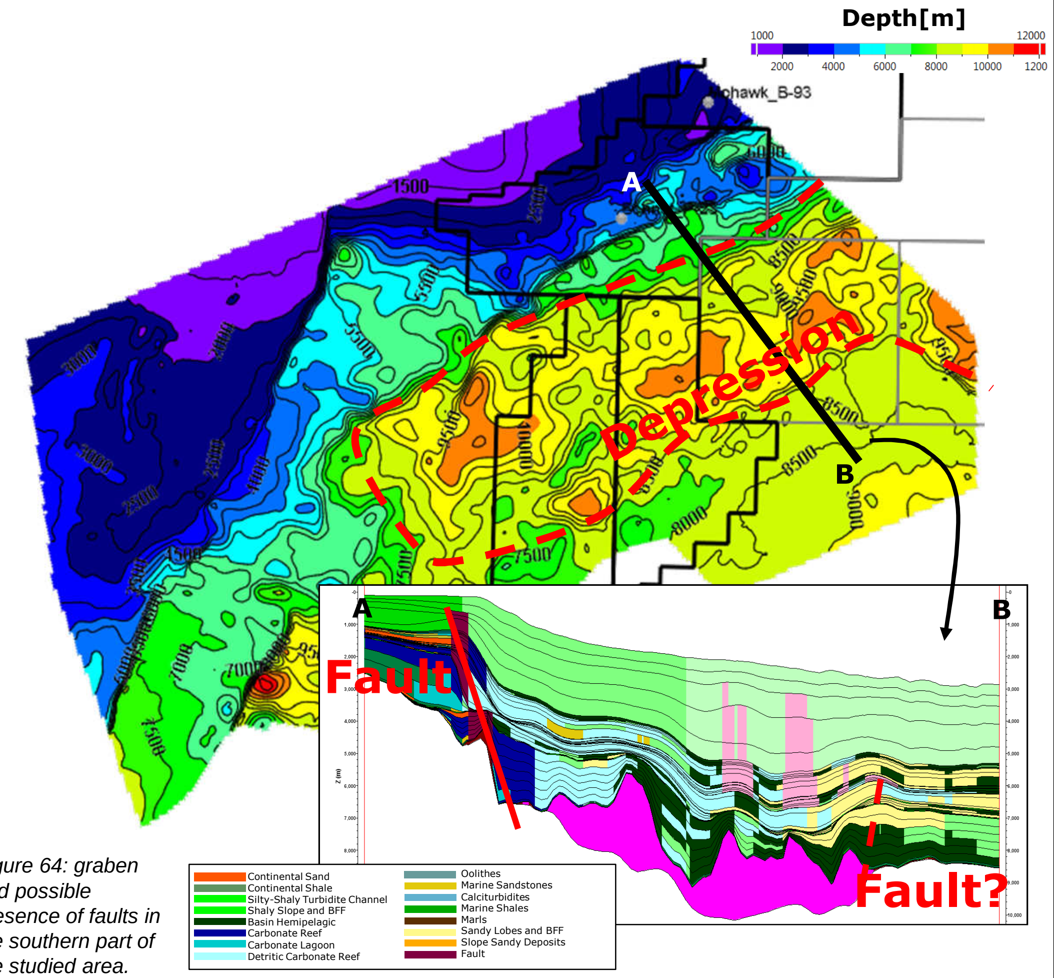


Figure 64: graben and possible presence of faults in the southern part of the studied area.

Petroleum System Chart of SW Nova Scotia Basin (Figure 65)

- Aptian and Valanginian SR are inmature.
- Tithonian and Callovian SR started their maturation and expulsion near 40Ma but their contribution to the system is limited.
- Low Jurassic Complex SR has an important contribution to the system. It started to be mature near 160Ma and contribute to lower reservoirs.
- Filling of Early Middle Jurassic reservoirs started near 100 Ma. The Filling of other reservoirs started at the maximum expulsion at 30Ma.

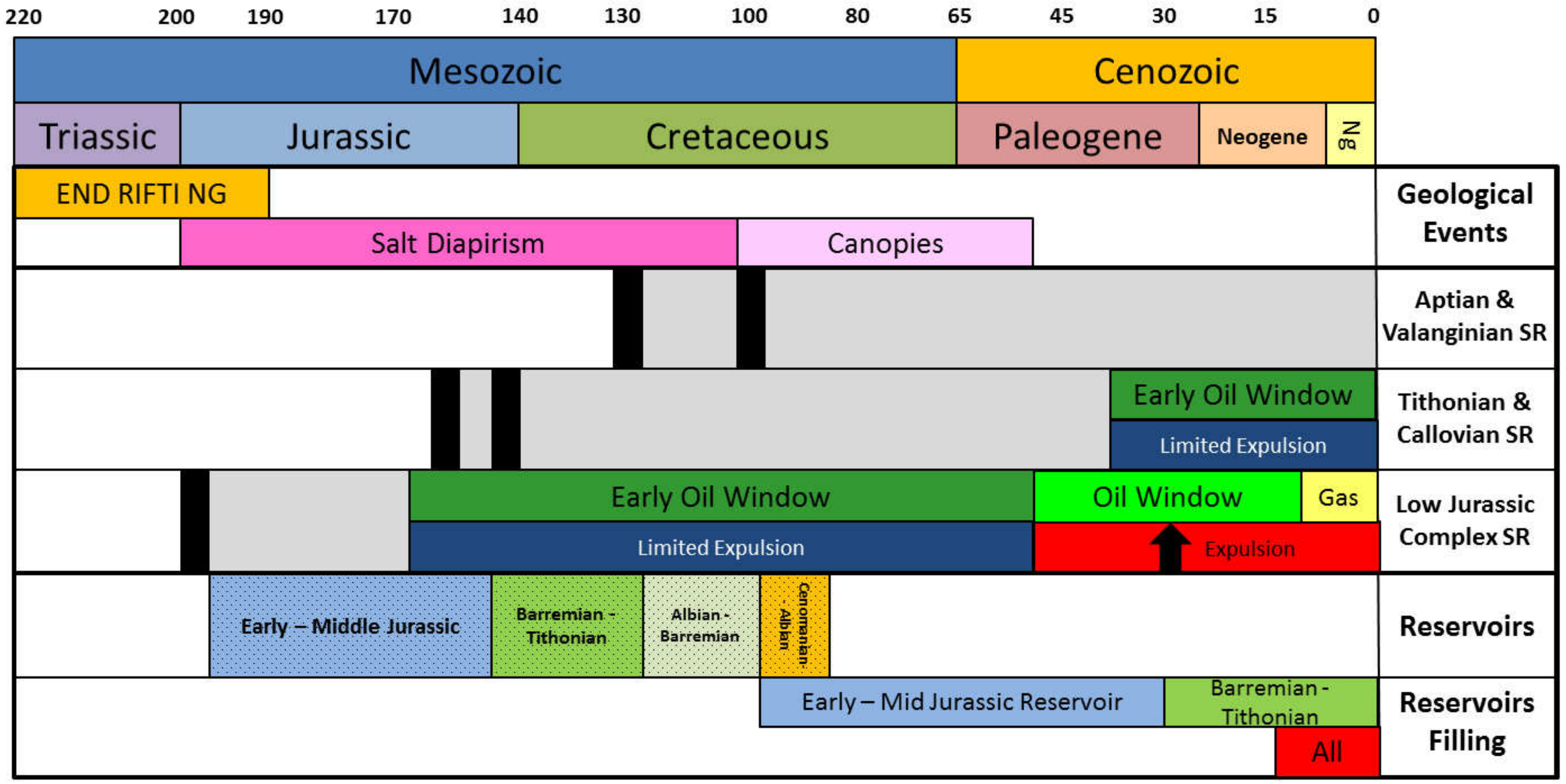


Figure 65: Petroleum System Chart of SW Nova Scotia Basin based on geological history and simulation results.

Conclusions on the Petroleum System Modeling

- Thermal calibration globally fits wells data and PFA 2011 results. However, the strong maturity at the bottom of Bonnet is still a major issue that does not seems to corresponds to the post-rift thermal relaxation. A probable explanation for this high maturity vitrinite values in Bonnet comes from recent publication on the effect of the HotSpot transit across the Nova Scotia shelf (Bowman en al., 2012). For this reason a second scenario for maturity was generated including a thermal event during the Albian intended to evaluate their impact on the source rock maturity.
- The SW Nova Scotia Basin exhibit suitable conditions for hydrocarbon generation and preservation. The hydrocarbon generation seems more probable for the Lower Jurassic interval (Plienbachian to Toarcian). Younger stratigraphic levels could have generation conditions locally in mini-basins synclinals.
- The hydrocarbon generation in the model comes mainly from a Lower Jurassic type II source rock. The presence of this source rock in the area needs to be confirmed.
- Generated hydrocarbons correspond to Oil with a API gravity ranging from 25 to 40 degrees.
- The most prospective area for the **lower Jurassic interval** extends East to West close to the base of the slope. Reservoirs correspond to carbonatic deposits and sandy turbidites basinward.
- The **Upper Jurassic**, **Upper Jurassic / Lower Cretaceous** and **Lower Cretaceous** plays correspond to stratigraphic traps, pinch-out against salt diapirs flanks and doming deformation at the top of salt diapirs. Reservoirs for these plays mainly correspond to calciturbidites and turbidites.
- **Main Risks**: The presence and quality of a lower Jurassic source rock is a major risk in the area, as well as the quality of reservoirs.

CHAPTER 7.4

BASIN MODELING – HOT SPOT SCENARIO

Early Cretaceous volcanism is widespread in the Scotian Basin. The volcanic rocks within wells, along the Scotian margins have been correlated to basalts flows outcrops (e.g. Scatarie Ridge) and dated from Hauterivian to Albian (Figure 66). These widespread volcanic activity indicates a regional and long-lived magma source, which implies a high regional heat flow. Thus the different seamounts observable on the oceanic crust result from this volcanic activity (e.g. Fogo Seamount, New England Seamount). Sleep (1990), Bowman et al. (2012) and Pe-Piper (2015) correlate them to a long-lived mantle plume system.
In the Georges Banks area, Sleep (1990) correlate the New England Seamount with the Withe Mountains range (igneous province). Thus, the hotspot seems to be active from the Jurassic (150Ma) with the White Mountains range to the late Early Cretaceous with the New England Seamounts (Figures 1 and 2).
This hotspot has some consequences on the stratigraphy records and on the petroleum system (e.g. Sable Basin, Bowman et al., 2012). The boyancy flux of this plume imply a regional uplift wich could be correlated to the Eraly Cretaceous Uncoformity (K137) and the Missisauga Sandstone. The potential uplift linked to this plume activity could be estimated from 500m to 1300m over 600km and seems to be a main local sedimentary input.

Moreover the high value of the heat flow could have an impact on the vitrinite reflectance and hence on the hydrocarbon maturation (E.G. sedimentary rocks of the Sable sub-basin, Bowman et al., 2012). The Figure 68 shows a simulated well and the impact of Heat Flow on vitrinite.

From Campbell (2005) it's possible to define a maximum plume diameter around 2000km with an extension of maximum heatflow between 500 to 700 km which cover all the study area (Figure 67).

From Sleep (1990), this hotspot could be comparable to La Reunion hotspot and 20-30% of current Hawaï hotspot.

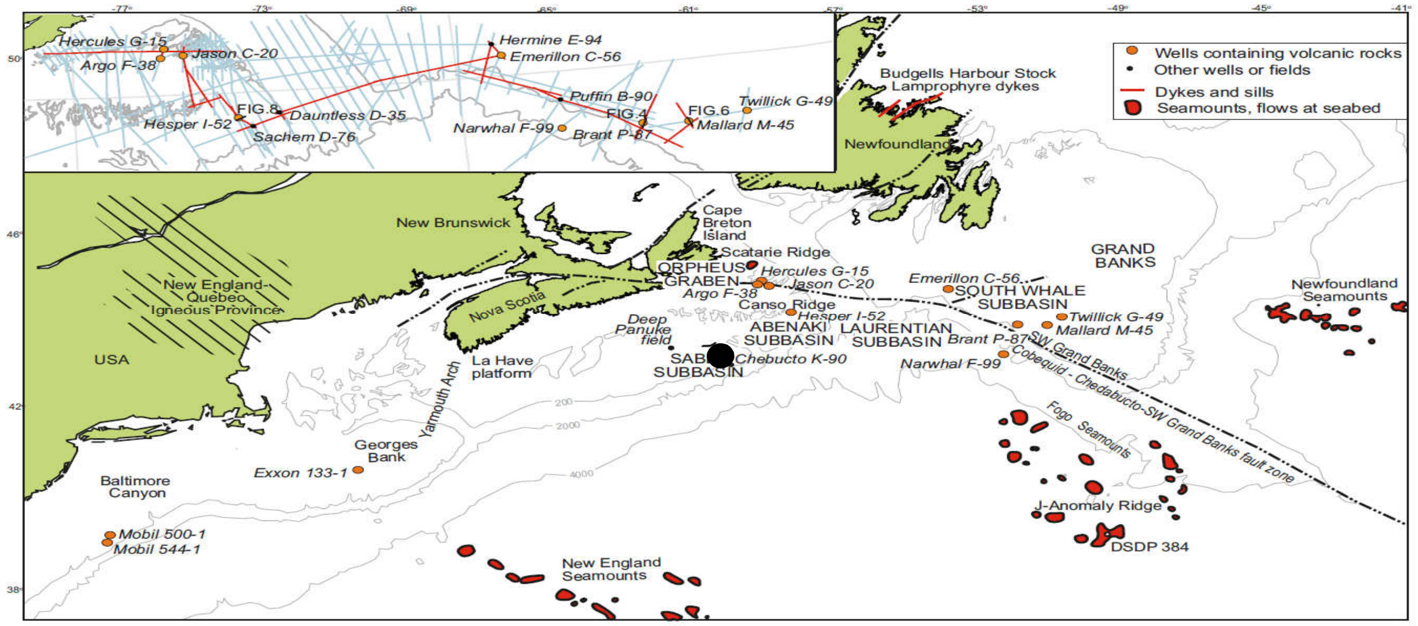


Figure 66: Regional extent of Early Cretaceous volcanism, showing wells penetrating volcanic rocks and the positions of the seamounts and flows at seabed (from Bowman et al., 2012). Chebucto well simulated in Figure 66 is located in Sable Basin (black point).

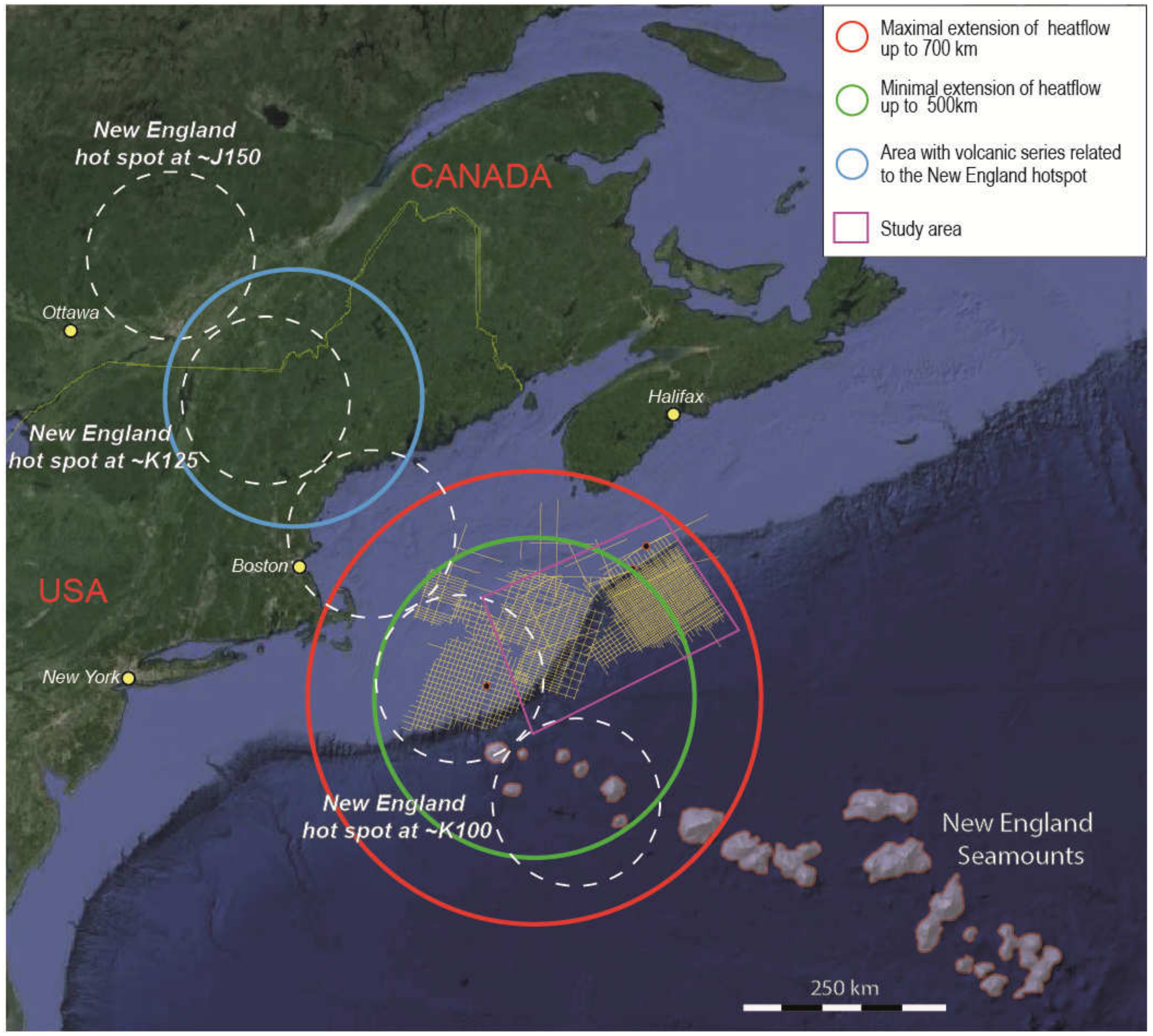


Figure 67: Map of the New England hotspot position throw the time and the maximum diameter and heat flow extension.

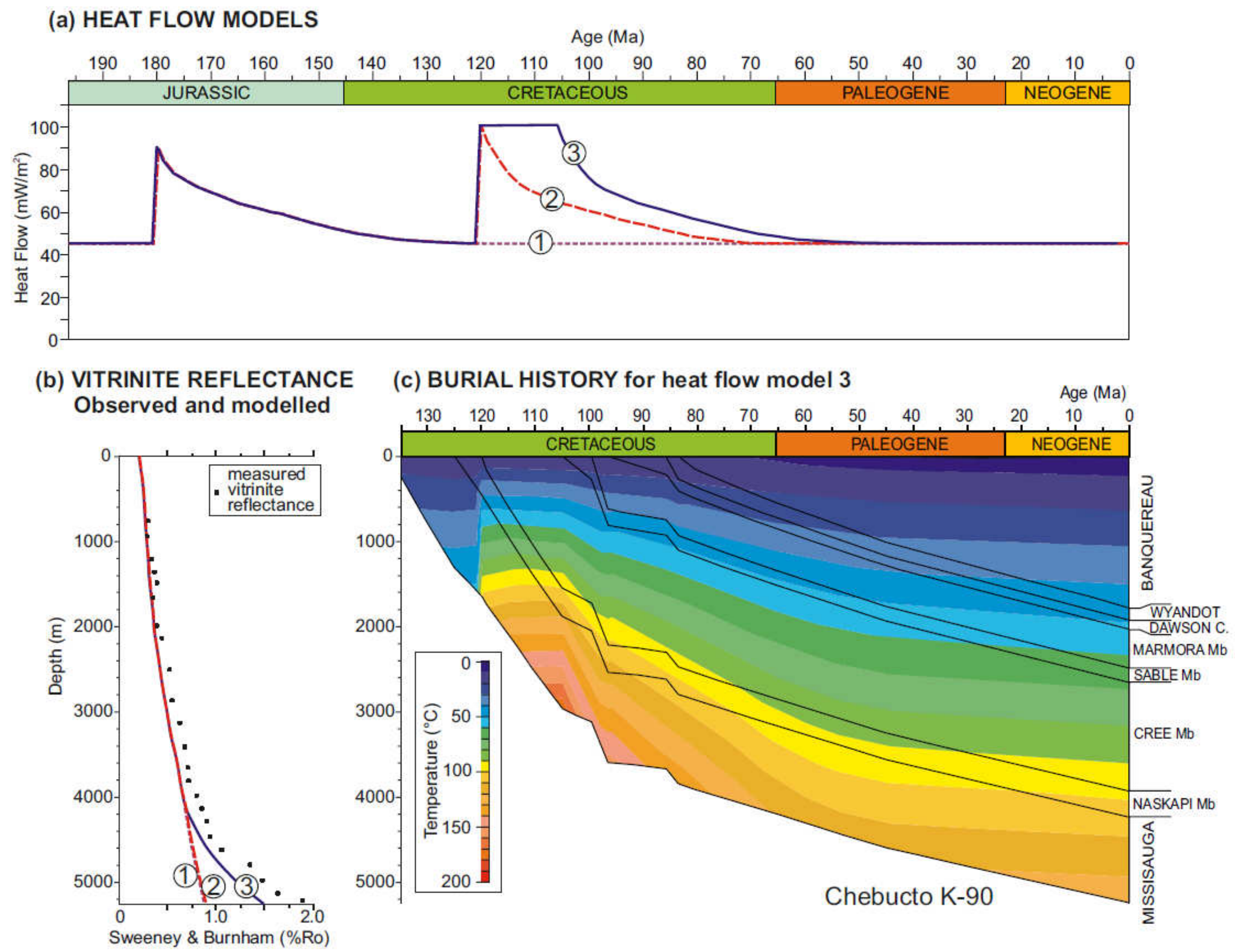


Figure 68: Summary of results of thermal modelling of the Chebucto K-90 well (see black dot on Figure 65): (a) Heat flow models ; (b) comparison of vitrinite reflectance observed with modelled; © burial history and predicted temperature for heat flow model 3. (From Bowman et al., 2012).

Thermal model with Hot Spot

Regarding the Figures 67 and 68, to simulate the hot spot a constant heat flow of 110mW/m2 was applied at the base of sediments from 130 to 101Ma (Figure 69).

A cooling effect was considered from 101 to 70Ma.

Until 130Ma and after 70Ma the normal thermal model was applied (crust model of Scenario 1).

Heat Flow (mW/m2) at base of sediments

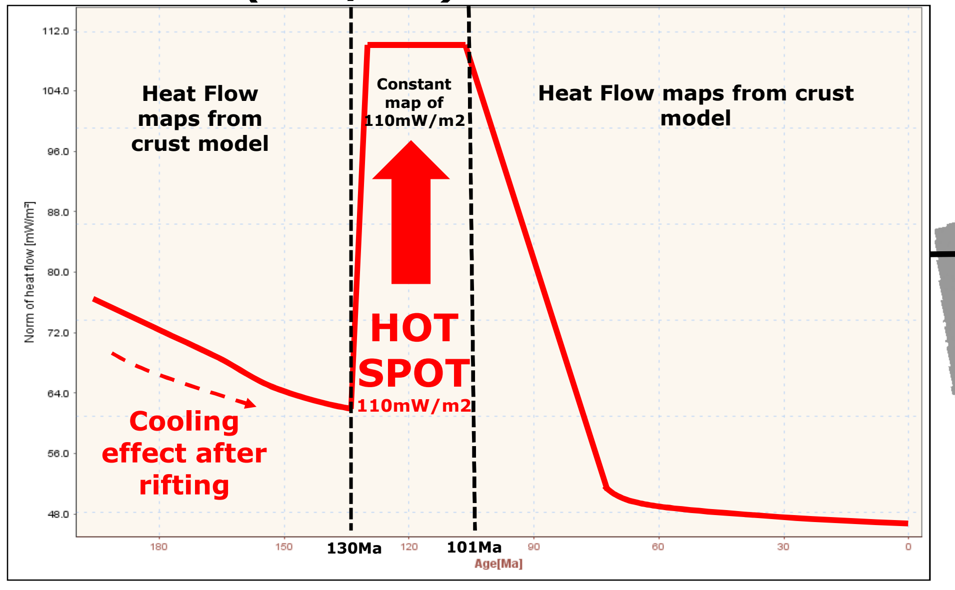
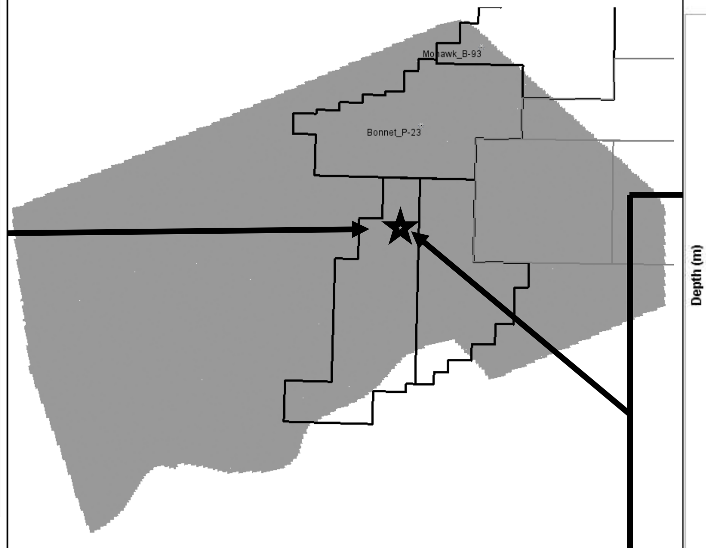


Figure 69: Heat flow model applied on the study, regarding the Figures 66 and 67.



BURIAL CURVE

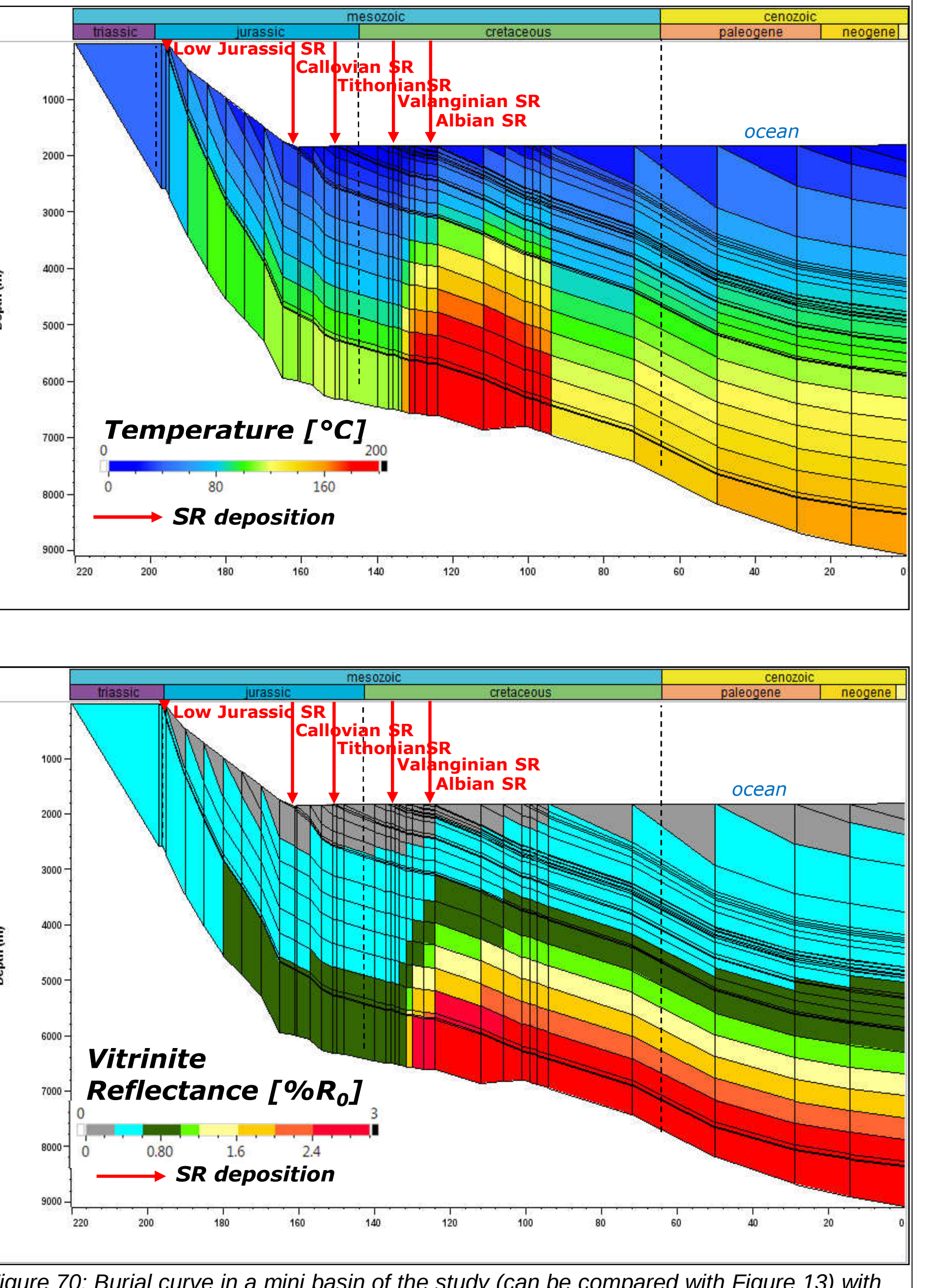
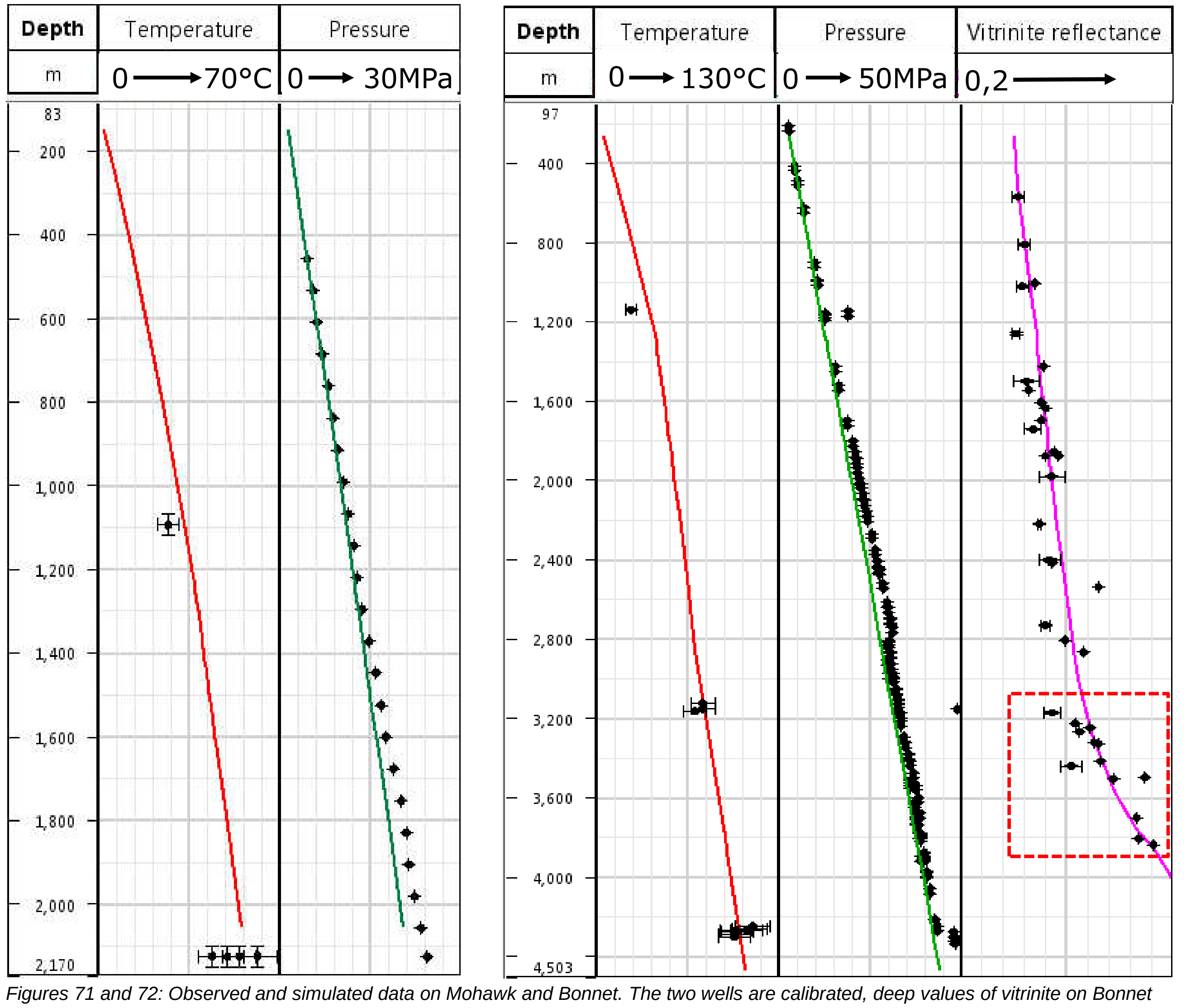


Figure 70: Burial curve in a mini basin of the study (can be compared with Figure 13) with simulated temperature and vitrinite. The hot spot effect is clearly visible with an increasement of temperature and vitrinite values.

Mohawk / Bonnet



Figures 71 and 72: Observed and simulated data on Mohawk and Bonnet. The two wells are calibrated, deep values of vitrinite on Bonnet are calibrated using the hot spot scenario.

Calibrations

The 3D model is calibrated (Figures 71 and 72) in pressure / temperature / maturity (vitrinite reflectance) with available well data (Mohawk and Bonnet). The simulation results from PFA 2011 were used to keep a coherency between the two models (as a part of the 2011 model cross our model).

Temperature and pressure from the simulation fits with the observed data, like the model without hot spot.

Regarding the deep vitrinites values on Bonnet (anomaly at 3200m, Figure 72), they were fitted perfectly with an hot spot starting at 130Ma and finishing at 101Ma.

Temperature

Temperature are relatively low in that basin. The temperature reaches 180°C -190°C in deepest part of the basin (due to salt movement, see depth map).
The Hot spot effect (Figure 70) is clearly identified from 130 to 101Ma with a temperature that can reach 300°C in deepest parts of the basin.

Vitrinite

Hot spot effect (Figure 70) has an important impact on Low Jurassic Complex SR that reaches the gas window abruptly at the beginning of the hot spot (130Ma). It has also a moderate impact on Callovian and Tithonian SR that reaches the oil window and the gas window in the deepest part.
Paleogene or later. Valaginina and Albian SRs are not mature.

With the hot spot effect, we can expect on affected SR an important secondary cracking (abrupt event) and gas generation.

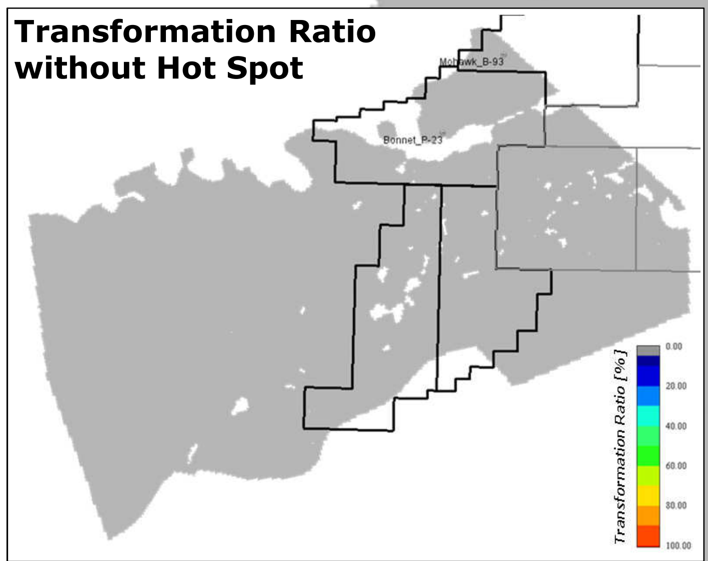
APTIAN SR

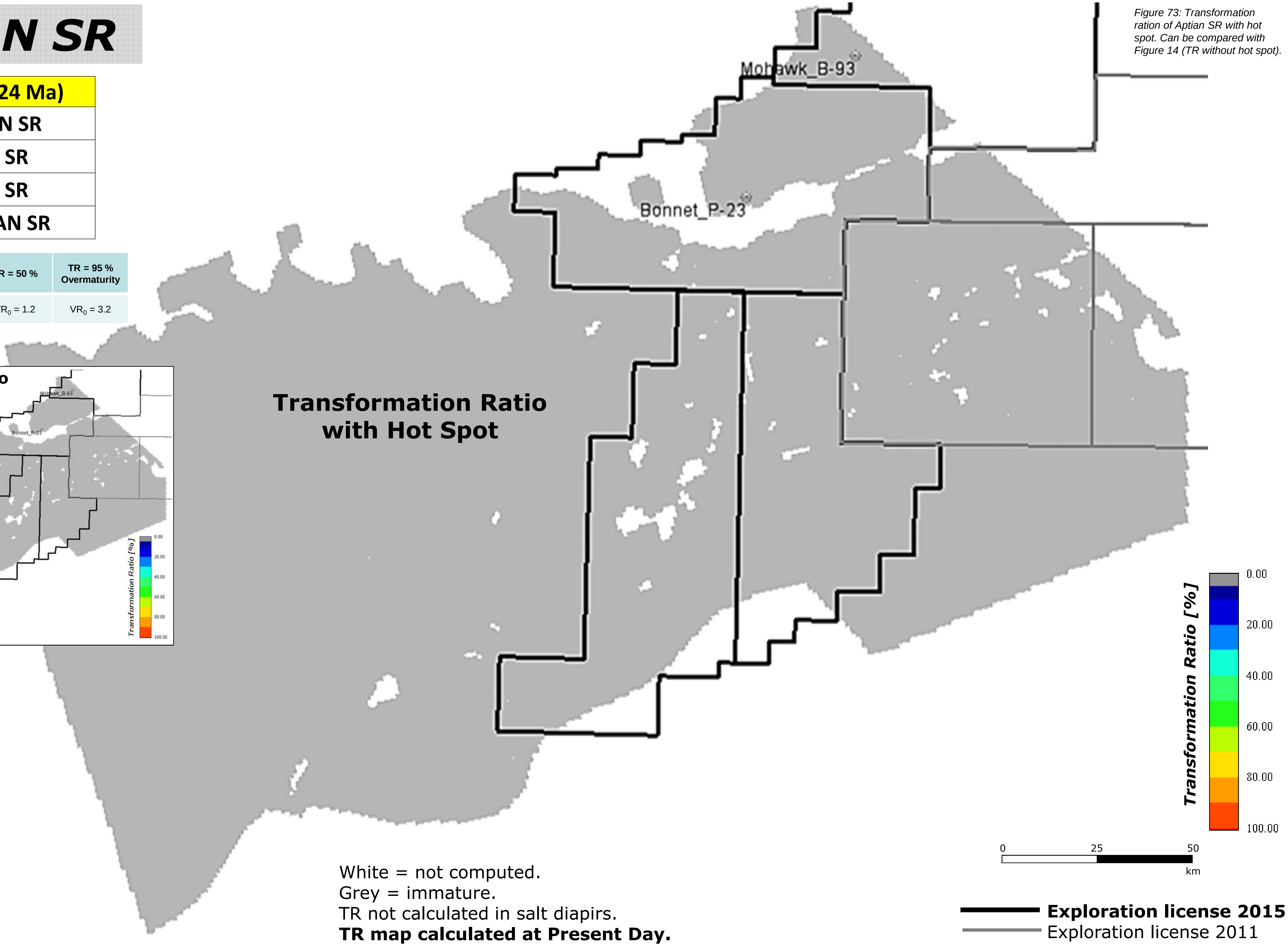
APTIAN SR (≈ 124 Ma)
VALANGINIAN SR
TITHONIAN SR
CALLOVIAN SR
PLIENSBACHIAN SR

Relationship TR / Vitrinite	TR = 5% Maturity (oil window)	TR = 50 %	TR = 95 % Overmaturity
Kerogen Type III	$VR_0 = 0.8$	$VR_0 = 1.2$	$VR_0 = 3.2$

Figure 73: Transformation ration of Aptian SR with hot spot. Can be compared with Figure 14 (TR without hot spot).

Transformation Ratio without Hot Spot





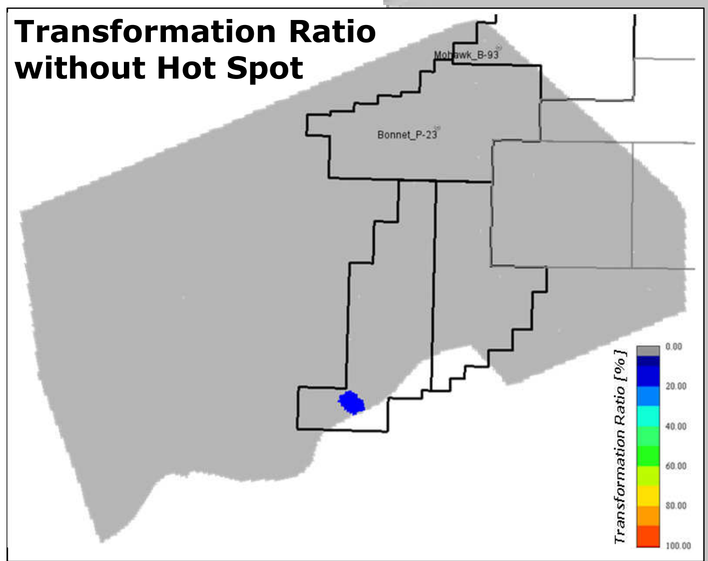
White = not computed.
Grey = immature.
TR not calculated in salt diapirs.
TR map calculated at Present Day.

Exploration license 2015
Exploration license 2011

VALANGINIAN SR

APTIAN SR
VALANGINIAN SR (≈ 136 Ma)
TITHONIAN SR
CALLOVIAN SR
PLIENSBACHIAN SR

Relationship TR / Vitrinite	TR = 5% Maturity (oil window)	TR = 50 %	TR = 95 % Overmaturity
Kerogen Type II	$VR_0 = 0.7$	$VR_0 = 0.9$	$VR_0 = 2$



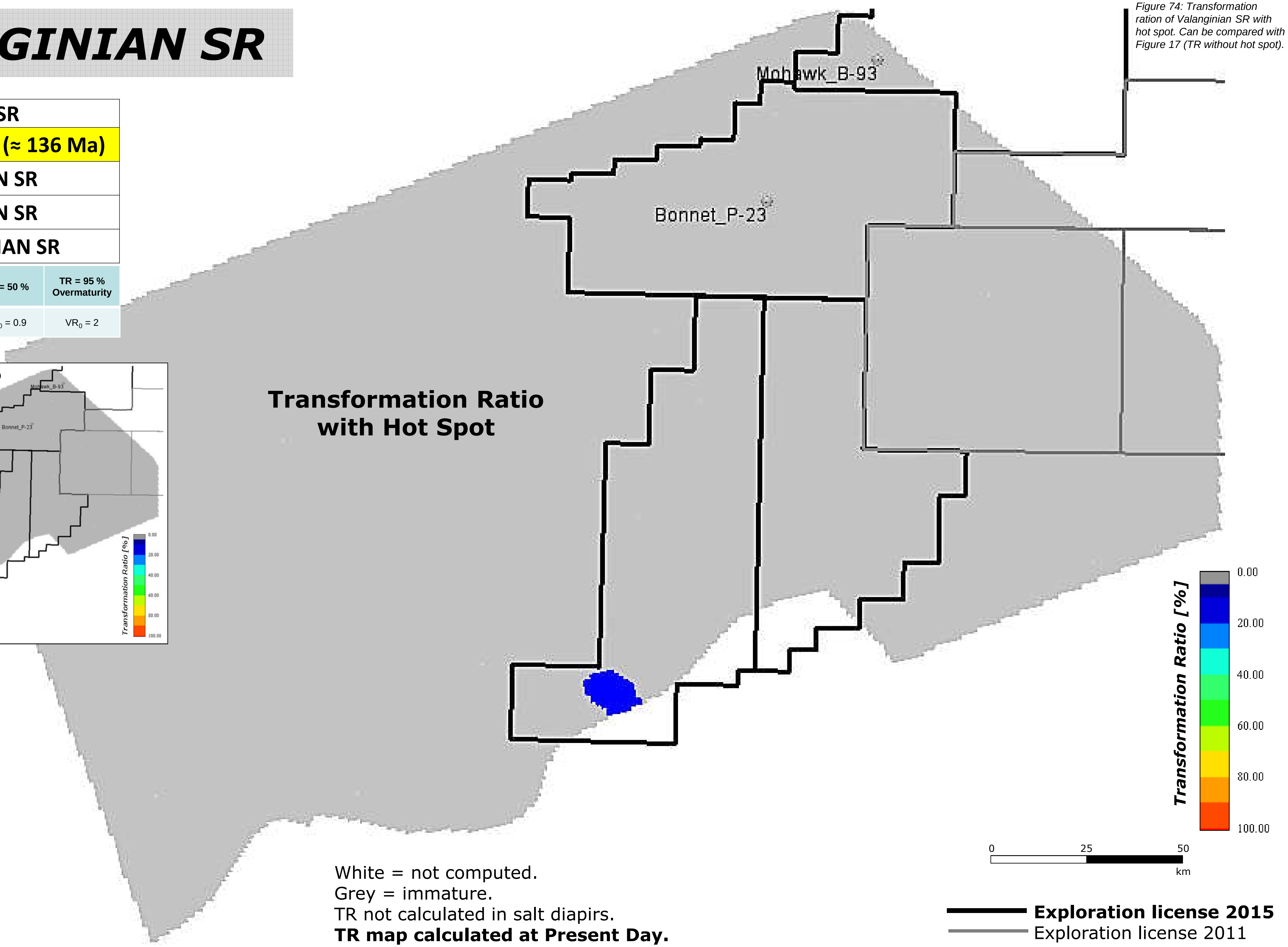


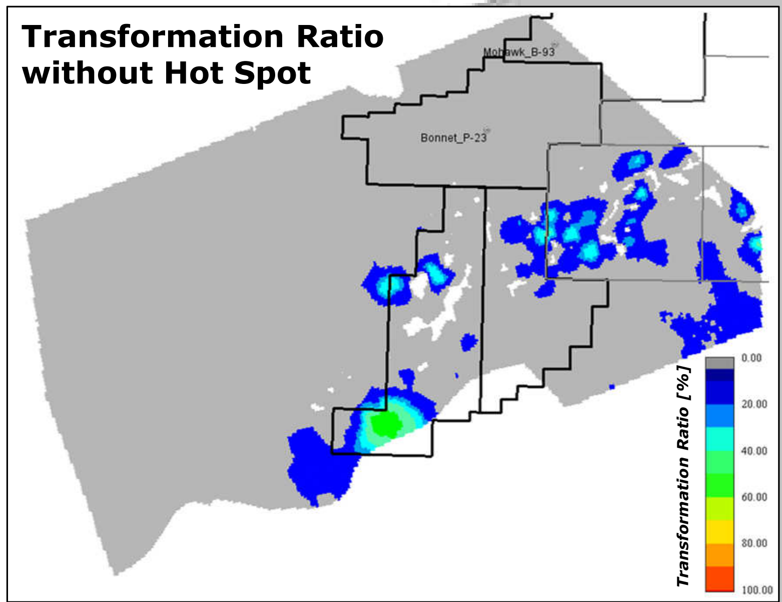
Figure 74: Transformation ration of Valanginian SR with hot spot. Can be compared with Figure 17 (TR without hot spot).

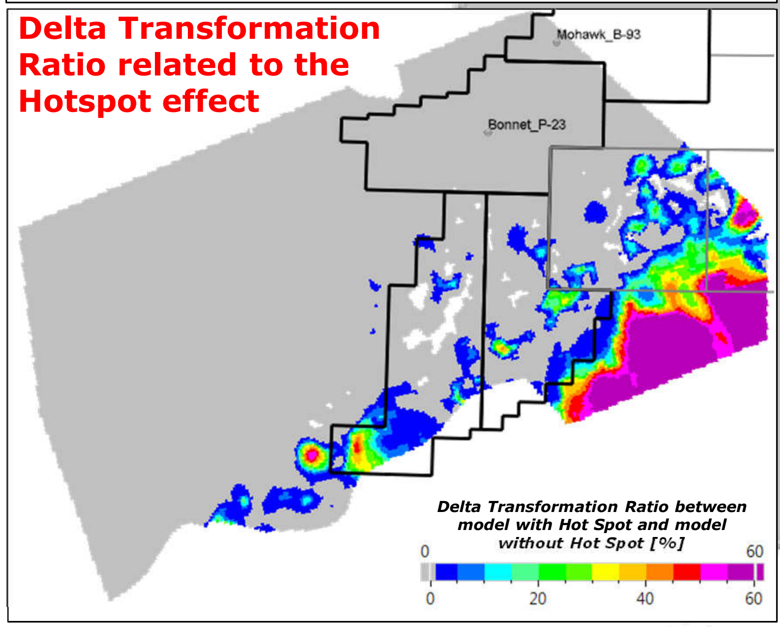
White = not computed.
Grey = immature.
TR not calculated in salt diapirs.
TR map calculated at Present Day.

TITHONIAN SR

APTIAN SR
VALANGINIAN SR
TITHONIAN SR (≈ 150 Ma)
CALLOVIAN SR
PLIENSBACHIAN SR

Relationship TR / Vitrinite	TR = 5% Maturity (oil window)	TR = 50 %	TR = 95 % Overmaturity
Kerogen Type II	VR_0 = 0.7	VR_0 = 0.9	VR_0 = 2





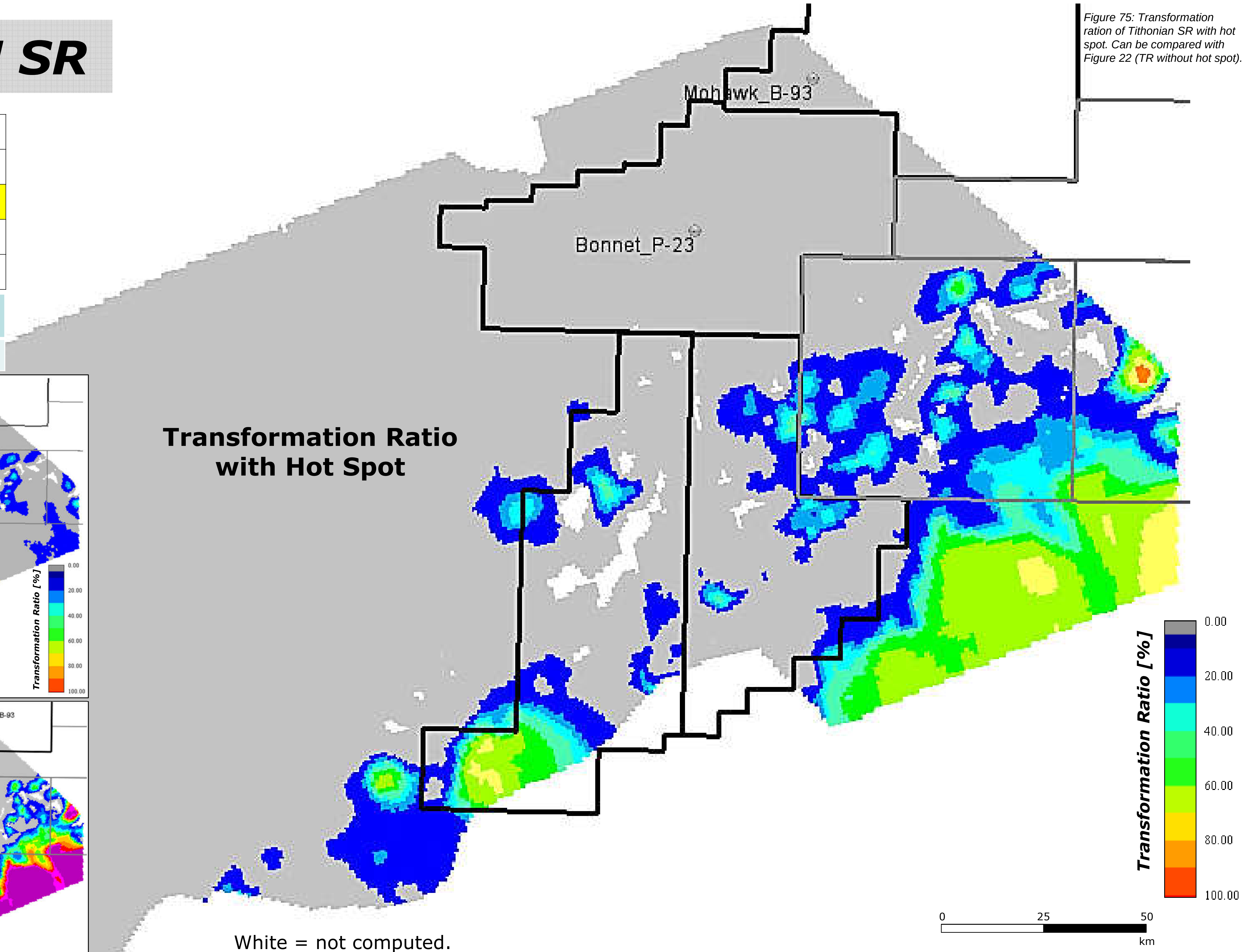


Figure 75: Transformation ration of Tithonian SR with hot spot. Can be compared with Figure 22 (TR without hot spot).

White = not computed.
Grey = immature.
TR not calculated in salt diapir.
TR map calculated at Present Day.

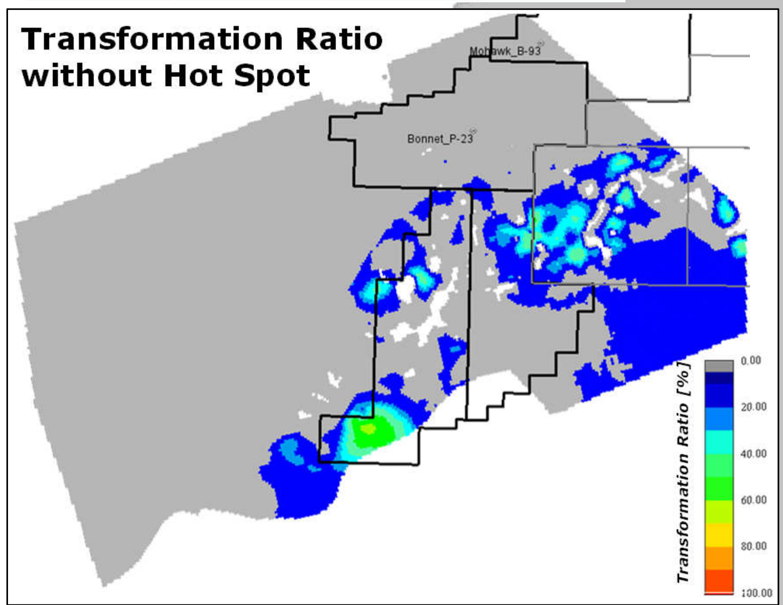
Exploration license 2015
Exploration license 2011

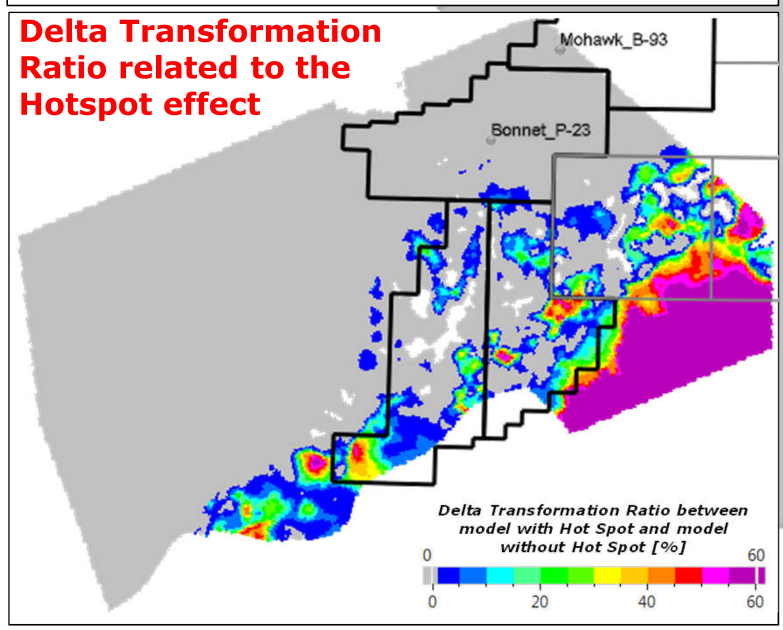
CALLOVIAN SR

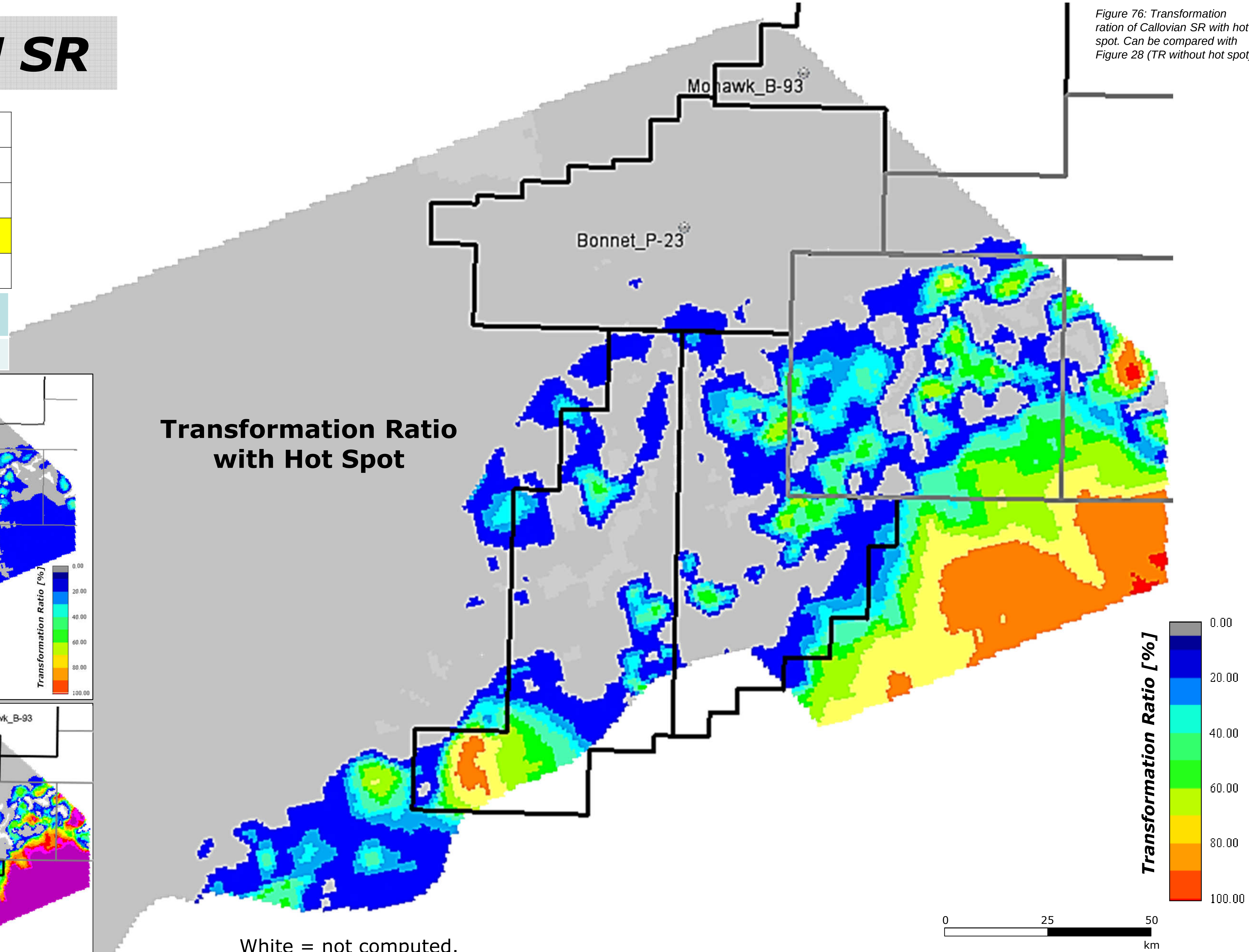
APTIAN SR
VALANGINIAN SR
TITHONIAN SR
CALLOVIAN SR (≈ 163 Ma)
Low Jurassic Complex SR

Relationship TR / Vitrinite	TR = 5% Maturity (oil window)	TR = 50 %	TR = 95 % Overmaturity
Kerogen Type II	VR_0 = 0.7	VR_0 = 0.9	VR_0 = 2

Figure 76: Transformation ration of Callovian SR with hot spot. Can be compared with Figure 28 (TR without hot spot).







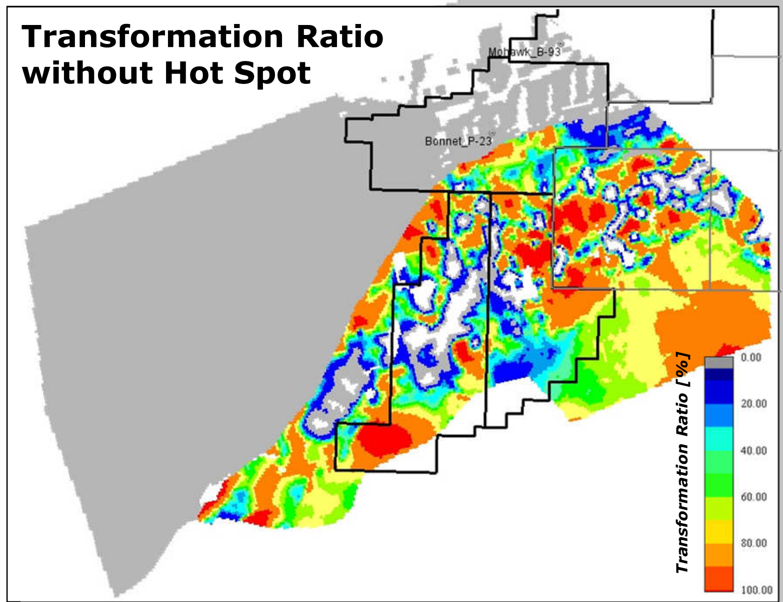
White = not computed.
Grey = immature.
TR not calculated in salt diapir.
TR map calculated at Present Day.

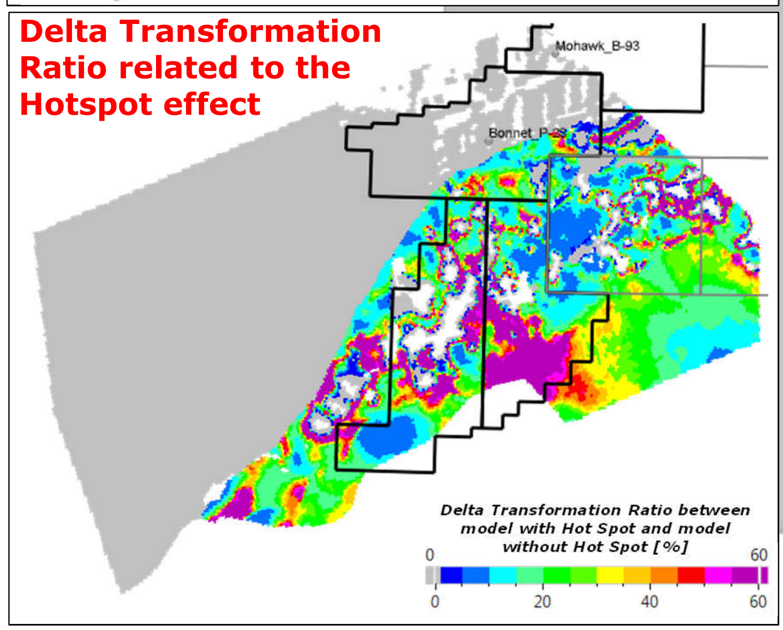
Exploration license 2015
Exploration license 2011

Low Jurassic Complex SR

APTIAN SR
VALANGINIAN SR
TITHONIAN SR
CALLOVIAN SR
Low Jurassic SR (≈ 196 Ma)

Relationship TR / Vitrinite	TR = 5% Maturity (oil window)	TR = 50 %	TR = 95 % Overmaturity
Kerogen Type II	$VR_0 = 0.7$	$VR_0 = 0.9$	$VR_0 = 2$





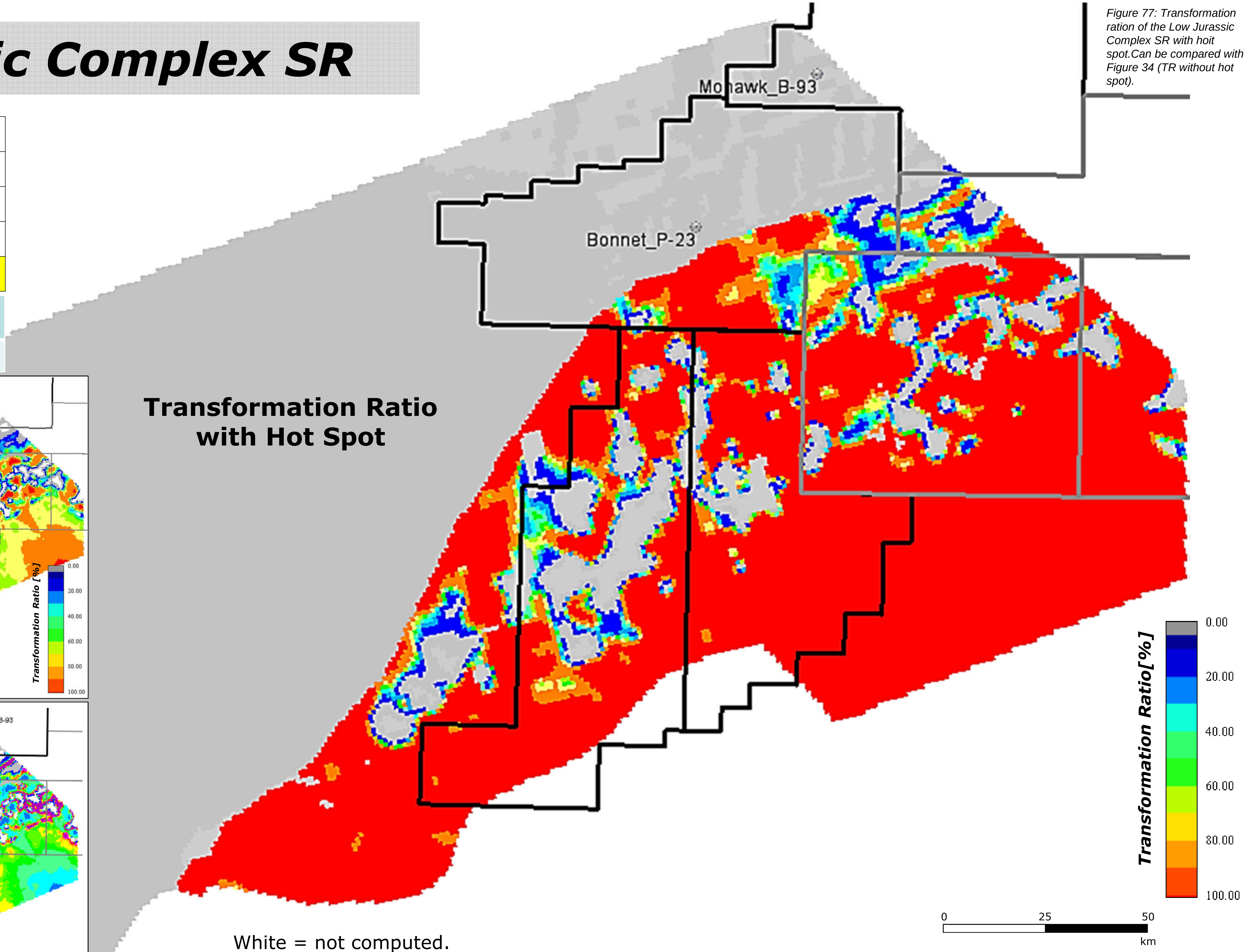


Figure 77: Transformation ration of the Low Jurassic Complex SR with hoit spot.Can be compared with Figure 34 (TR without hot spot).

White = not computed.
Grey = immature.
TR not calculated in salt diapir.
TR map calculated at Present Day.

Exploration license 2015
Exploration license 2011

Conclusions of the Hot Spot Scenario

- Results on the modelling of a thermal disturbance during the Aptian with a heat flow up to 110 mw/m^2 allow to obtain a maturity curve that fits vitrinite data in Bonnet (Figure 72). This suggest that high maturity vitrinite values at the bottom interval of Bonnet can be reproduced as the effect of a thermal disturbance event. However, a better comprehension of this kind of thermal events probably linked to the HotSpot's transit through the Nova Scotia margin will require more studies at regional and local scales.

- The probable presence of a thermal event at the end of the Early Cretaceous would have un strong impact on the maturity of source rocks in the Jurassic interval of the Shelburne Sub-Basin. This would notably be evidenced by an early maturation and expulsion than in the reference scenario without HotSpot.

- The effect of a HotSpot thermal event would not only have an impact on maturity and timing of expulsion but probably also on the hydrocarbon phase and distribution. At the different stratigraphic levels. A more detailed description of their effect on expelled hydrocarbons can be assessed if required.

Bibliographic References

Bowman, S.J., Pe-Piper, G., Piper, D.J.W., Fensome, R.A., King, E.L., 2012. Early volcanism in the Scotian Basin, Can. J. Eartch. Sci., vol. 49, 1523-1539.

Dehler, S.A., Welford, J.K., 2013. Variations in rifting style and structure of the Scotian margin, Atlantic Canada, from 3D gravity inversion, *from* Mohriak, W. U., Danforth, A., Post, P. J., Brown, D. E., Tari, G. C., Nemcok, M.&Sinha, S. T. (eds) 2013. Conjugate Divergent Margins. Geological Society, London, Special Publications, 369, 289–300.

Campbell, I.H., 2005. Large igneous provinces and the mantle plume hypothesis. Elements, vol.1, 265-269.

Sleep, N.H., 1990. Monteregian Hotspot Tack: A long-lived Mantle plume. Journal of Geophysical Research, vol. 95 (B13), 983-990.