CHAPTER 7

BASIN MODELING

Objectives

The basin modeling study aims at:

✓ Improving knowledge on the **active petroleum systems** of offshore Nova Scotia:
  - Integration of petroleum systems elements into the model (source rock layers, plays systems, etc.)
  - Thermal modeling and pressure modeling
  - Description of migration and migration process
  - Simulation of maturity/expulsion/migration/entrapment/preservation timing

✓ Estimating **hydrocarbon volumes** within the study area:
  - **Expelled volumes** for 6 zones subdividing the study area, for each source rock.
  - **In Place volumes** for the 6 zones, and by plays system. Volumes estimated are unrisked.

The elements of the Petroleum Systems integrated to the models come from the geological model developed in previous Chapters (Chapter 4 – "Petroleum Geochemistry"; Chapter 5 – "Seismic Interpretation"; Chapter 6 – "Tectono-stratigraphic Evolution and Petroleum Systems"). The modeling is performed with the Temis Suite® software (Temis 1D®, 2D®, 3D®).

Main results

Temis 1D®

gives a first overview of thermal and maturity constraints for the model calibration in drilled areas. Ten wells are considered.

Temis 2D®

Known petroleum fields in the Sable Sub Basin (Zone 3) are well modeled. It also appear that (from the West to the East):

- Line 1100 (Zone 1 and 2). Maturity is insufficient for effective generation/migration. The Pliensbachian source rock (SR) is mature between Lines 1100 and 1400 providing effective charge in the mini-basin area.
- Line 1400 (Zone 1 and 2). HC migration/accumulation is possible along the slope (Pliensbachian SR mature down the slope), up to the Oxfordian. However, HCs cannot migrate beyond the shelf break onto the carbonate platform (small drainage areas). A few small accumulations appear around and above salt diapirs.
- Line 1600 (Zone 3 and 4). Accumulations exist both in the slope and on the carbonate platform, and locally in the deep basin, thanks to a high maturity level. Different kind of traps may exist depending on the sector: the biggest ones would be located bellow salt canopies (basinward).
- Line 2000 (Zone 5 and 6). Accumulations exist both in the slope and on the carbonate platform. The largest accumulations are deep, due to a limited migration efficiency.

Temis 3D®: Maturity and expulsion modeling

The main contributors at the scale of the Basin are the Tithonian SR (48% of expelled HC) **and the Pliensbachian SR** (32% of expelled HC, of which 43% is expelled oil). The Callovian SR and Valanginian SR are less significant contributors (respectively 15% and 11% of expelled gas). The contribution of the Aptian SR is negligible. The Pliensbachian SR is the only typically oil-prone source rock, while the Tithonian SR is oil/gas-prone and the others are essentially gas-prone.

Maturation of the **Tithonian SR** started in Early Cretaceous time in zones 3, 4, 5 and 6. On the contrary, maturation started late in the western area (zones 1 and 2). Overmaturity occurred very early (Early Cretaceous) in the deepest part of zones 3, 5 and 6 that are located on the slope.
Strong expulsion occurred in zones 3, 5, and 6, in the slope and the platform margin, where the expelled quantity exceeds 1 Mt/km^2, equivalent to 7.8 Mboe/km^2, for a total of 360 Bboe expelled for zones 3, 5 and 6. Expulsion is also significant in Zone 4. Elsewhere expulsion is limited and cannot contribute significantly to HC accumulations (except locally in salt mini-basin of Zone 2).

Maturation of the **Pliensbachian SR** started early in Jurassic time in zones 3 and 5. In the easternmost part of Zone 3, in Zone 4 and in the deepest parts of zones 1 and 2, maturation started during Early Cretaceous time. Elsewhere, in zones 1 and 2, maturation started much later, in Paleogene time. Overmaturity level was reached very early in zones 3, 4, and 5 (Jurassic to Early Cretaceous), may create a **timing issue with regard to migration and accumulation/trapping**.
Expulsion mainly occurred in zones 3 and 5 and in the north of zone 4 where the quantity exceeds 1 Mt/km^2, equivalent to 7.8 Mboe/km^2, for a total of 180 Bboe expelled for zones 3, 4 and 5. **In the eastern part of Zone 1 and locally in scattered areas of zones 1 and 2** (salt mini basins) **expulsion is significant,** locally in excess of 1 Mt/km^2, equivalent to 7.8 Mboe/km^2, for a total of 130 Bboe expelled for zones 1 and 2.

Zones with largest amount of expelled HC are: **Zone 3 (31%)**, **Zone 6 (22%)**, Zone 5 (17%), Zone 4 (14%), Zone 2 and Zone 1. **About 60% of expelled HCs are gas.**

Temis 3D®: Migration modeling

At the scale of the Basin, about 2-3% of "expelled hydrocarbons" through geological times are "in place" at present day.
The **Tithonian SR** is a significant contributor in all zones, all play systems (except the Early-Middle-Jurassic play system). At the scale of the basin it sources 1/2 of the total amount of hydrocarbons in place.
The **Pliensbachian SR** is locally a very significant SR (up to 3/4 of the total amount of hydrocarbon in place in zones 1 and 2).

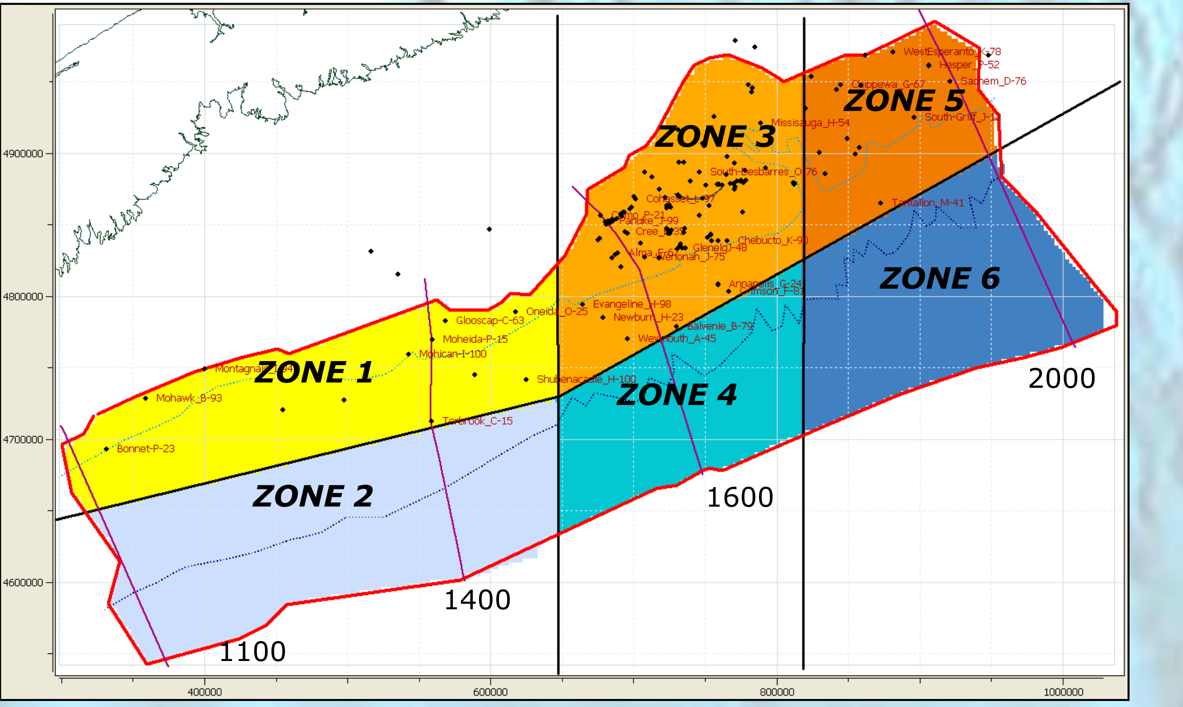
The richest zone is Zone 3 which contains the Sable Sub-basin (about 1/4 of the total calculated amount of HC in place). About 2/3 of the total amount of HC in place are in "shelf zones" (1, 3, 5).

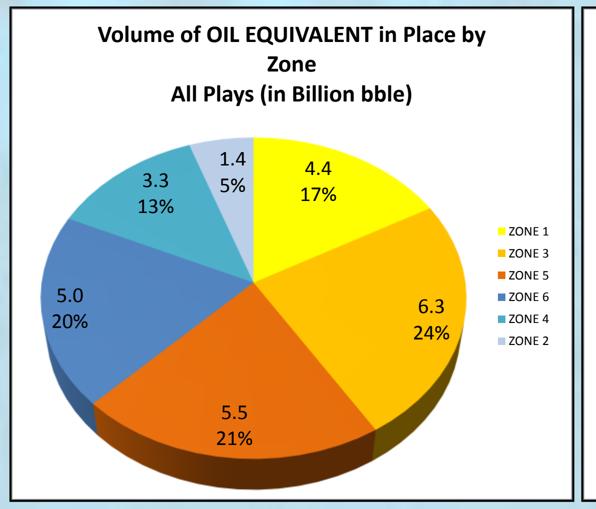
70% of HCs in place are gas, however the average GOR change between the 6 zones (between 5000 and 25000 scf /bbl). Zone 3 and 6 are particularly rich in gas, while zone 1 and 2 contain more oil than gas. Such differences come from changes in maturity/secondary cracking intensity, and in source rock contributions. As a consequence about 1/3 of the oil in place at the scale of the basin would be trapped in Zone 1.

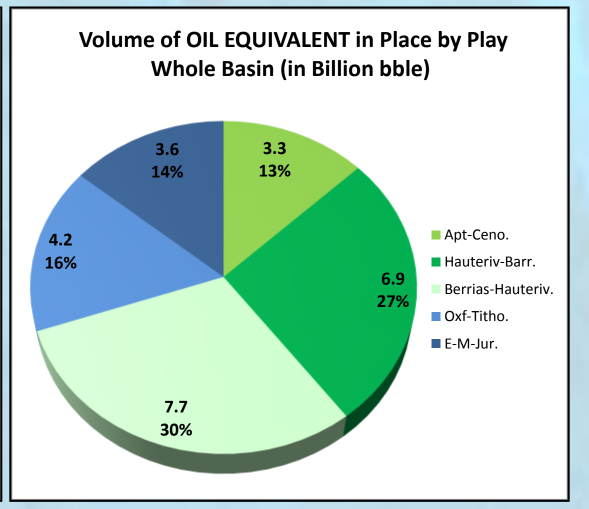
At the scale of the basin the richest plays are the **Hauterivian-Barremian sequence** (K130-K123) and the **Berriasian-Hauterivian** sequence (J150-K130). Both plays contain about 2/3 of the total amount of HC in place. In the Sable Sub Basin, where the same distribution is observed, these sequences correspond to the Upper Mississauga and the Middle-Lower Mississauga reservoir units.

- Zones 3 and 5 have first ranks in Albian-Cenomanian and Hauterivian-Barremian play systems.
- Zone 6 reaches the first rank in the Berriasian-Hauterivian play system.

Temis® volumes are consistent with previous hydrocarbon volume estimations from various studies.







HC VOLUMES IN PLACE - UNRISKED (surface condition)

By ZONE	TOTAL GAS volume in surface (Tcf)	TOTAL OIL volume in surface (Mbbl)	TOTAL OIL EQUIVALENT volume (Billion bble)	GOR (scf / sbbl)
ZONE 1	14	2470	4.4	6000
ZONE 3	35	1130	6.3	31000
ZONE 5	27	1650	5.5	16000
ZONE 6	26	1090	5.0	24000
ZONE 4	16	990	3.3	16000
ZONE 2	4.2	820	1.4	5000
Whole Basin	121	8150	26	15000

CHAPTER 7-1

BASIN MODELING – TEMIS 1D

1D Modeling

The intent of 1D modeling was to have a first pass at testing the consistency of all input data such as temperature, pressure, maturity, burial history, and the thermal history induced by the lithosphere modifications during rifting. A critical answer expected from these models is the role of unconformities, whether deposition/erosion or hiatus, in affecting maturity and timing of hydrocarbon generation.

For this purpose, 1D modeling was carried out on 10 out of the 20 reference wells. The 10 models are displayed in this Chapter.

Input data are:

- Rifting age between 225 Ma and 200 Ma.
- Lithosphere data from SMART lines 1, 2, 3 and OETR 2009 (see below)
- Well stratigraphy derived from the biostratigraphic scheme developed in this study to reconstruct the burial history at the well locations (see Enclosures).

Model outputs shown below are:

- Maturity calibration
- Temperature calibration
- Pressure calibration
- Burial and maturation history (modeled Vitrinite Reflectance versus time)
- Transformation ratio for the main source rocks through time in order to estimate an hydrocarbon expulsion time.

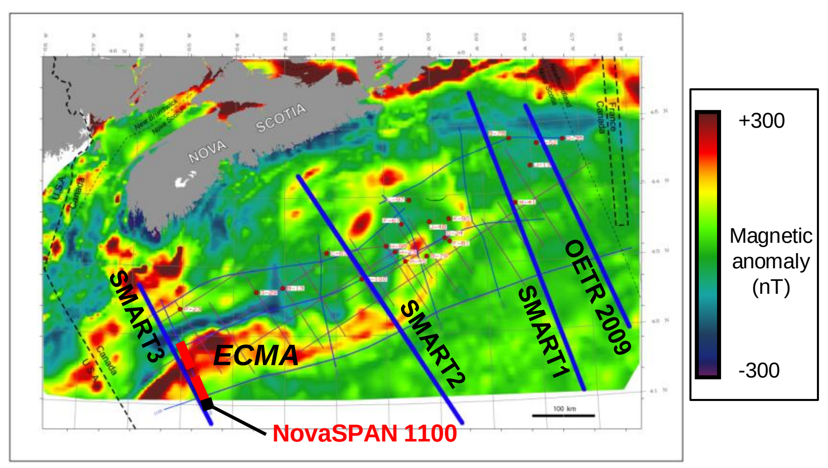


Figure 1: Location of the wide-angle seismic line on the regional magnetic anomaly map

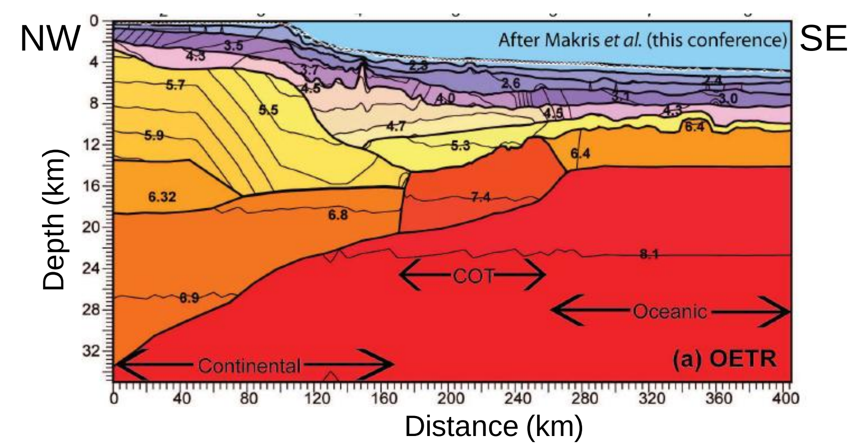


Figure 2: P-Wave velocity model – line OETR 2009

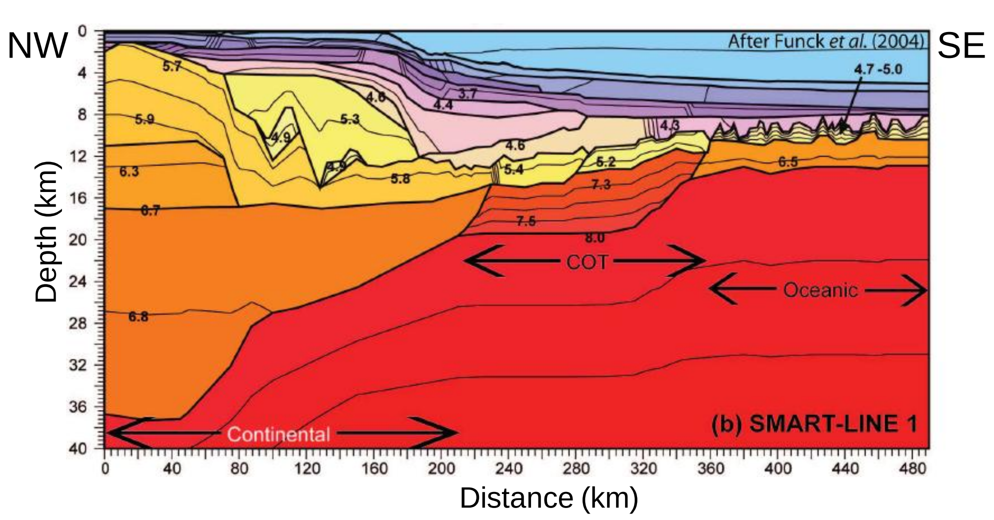


Figure 3: P-Wave velocity model – SMART line 1

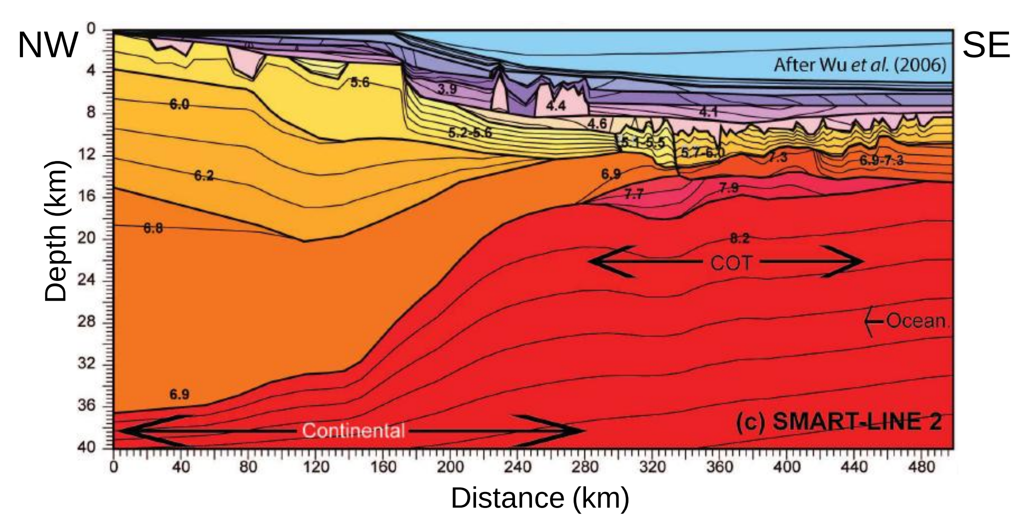


Figure 4: P-Wave velocity model – SMART line 2

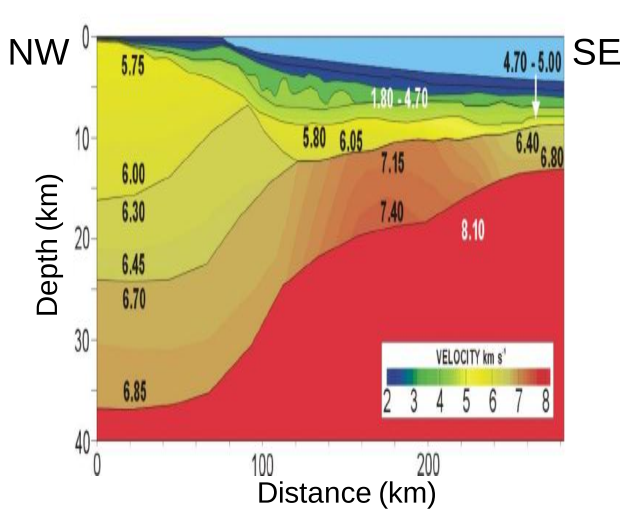
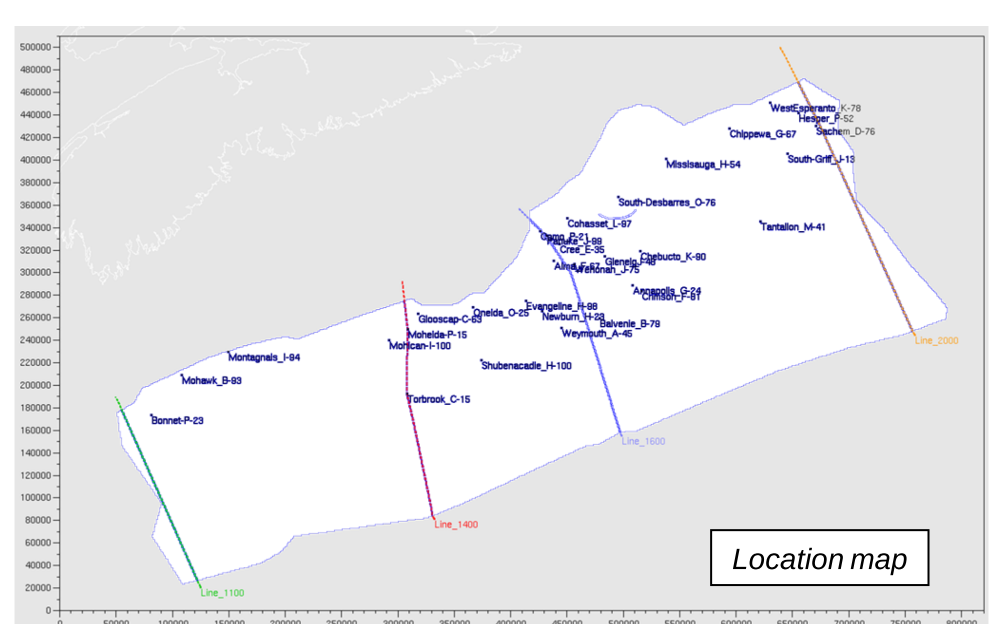


Figure 5: P-Wave velocity model – SMART line 3

The thermal model developed for the modeled wells is based on the rift history derived from the SMART and OETR 2009 lines. The lithosphere configuration applied to each model is projected from the closest line to the modeled location.



Cohasset L-97

Modeled maturity calibrates well with Vitrinite Reflectance (VR) data from Mukhopadhyay (1991). Calibration against Avery's data (GSC on-line Basin Database) was attempted, but no reasonable combinations of the petroleum system elements can reproduce them. Therefore Mukhopadhyay's Vitrinite Reflectance data are considered most reliable for the Cohasset L-I-97 well.

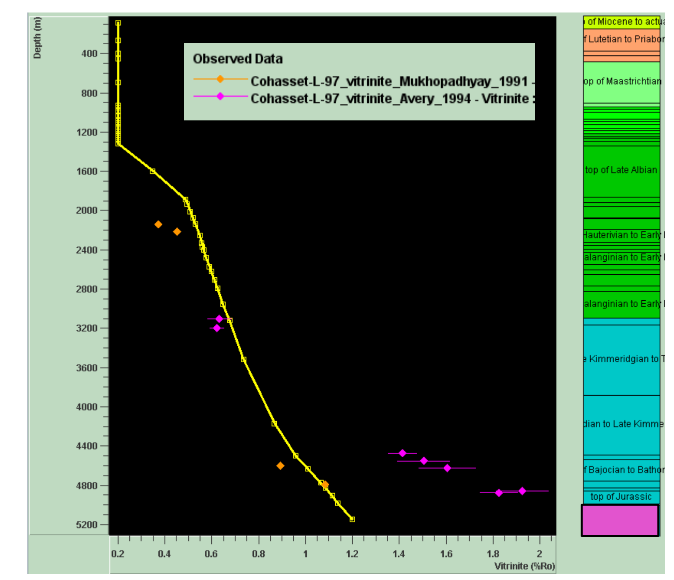


Figure 7: Maturity calibration

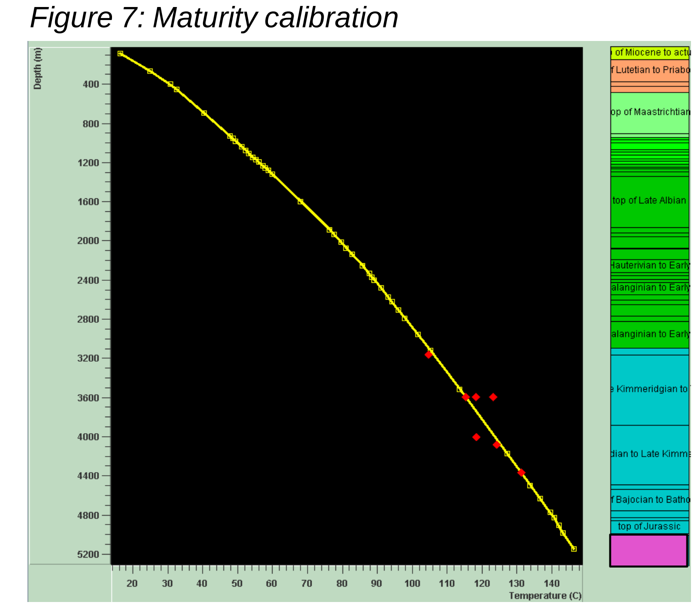


Figure 8: Temperature calibration

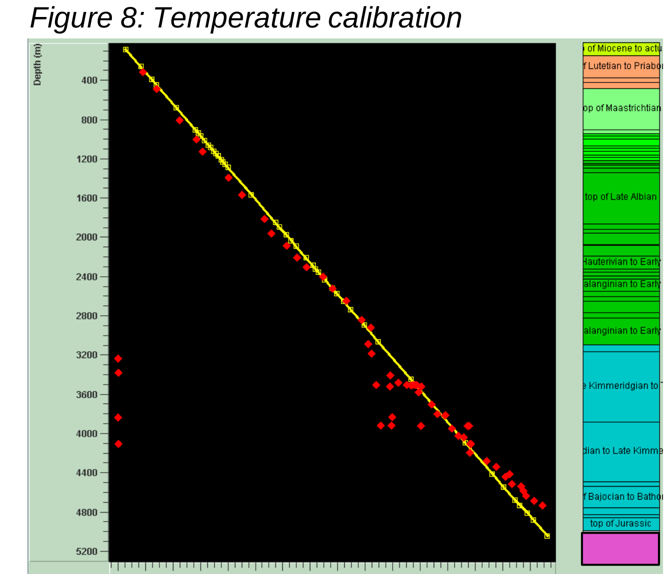
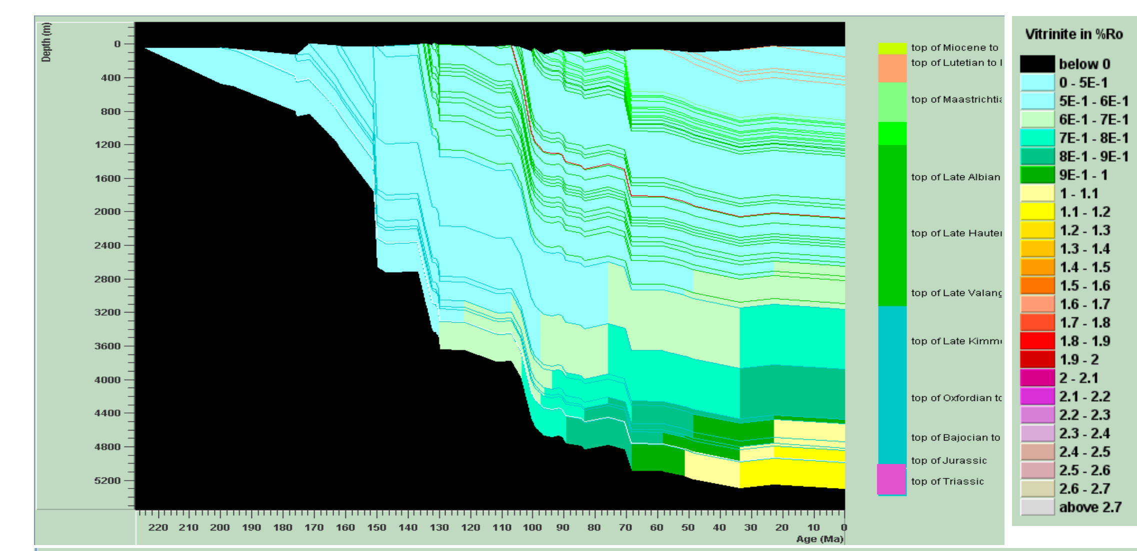


Figure 9: Pressure calibration

Horizons #	Age	Intermediat...	Unconf	Name	Col	Layers #	Name	Col	Depth (m)	Eroded (m)	Litho	Thickness (m)
1	0			Sea Bottom		1	Miocene to ...		21.6		shale'	130.4
2	23	0		Oligocene ...		2	Oligocene ...		152		shale'	0.0
3	33.9	0		Lutetian to ...		3	Lutetian to ...		152		2sa_98sh	230.0
4	48.6	0		Ypresian		4	Ypresian		382		20sa_80sh	41.48999
5	51.59	0		Ypresian		5	Ypresian		423.49		15sh_85sash	61.51001
6	58.5	0		Base Tertia...		6	Base Tertia...		485		shale'	0.0
7	68.5	0		Maastrichti...		7	Maastrichti...		485		50sa_50sh'	422.0
8	70.6	0		Campanian		8	Campanian		907		2sa_98sh	39.0
9	76	0		intra-L. Cre...		9	intra-L. Cre...		946		shale'	0.0
10	83.5	0		Turonian to...		10	Turonian to...		946		sandstone'	19.5
11	84.61	0		Turonian to...		11	Turonian to...		965.5		chalk'	35.96997
12	89.5	0		Turonian SB		12	Turonian SB		1001.47		14li_86sh	65.30005
13	90.39	0		Turonian to...		13	Turonian to...		1066.77		dolostone (ea...	22.97998
14	91.7	0		Turonian to...		14	Turonian to...		1089.75		14li_86sh	33.25
15	94	0		L. Cenom ...		15	L. Cenom ...		1123		shale'	39.5
16	96.5	0		Cenomanian		16	Cenomanian		1162.5		34li_66_sh	18.46997
17	97.51	0		Cenomanian		17	Cenomanian		1180.97		shale'	31.03003
18	99.6	0		Late Albian		18	Late Albian		1212		7li_93sh	36.819946
19	99.83	0		Late Albian		19	Late Albian		1248.82		sandstone'	11.300049
20	99.91	0		Late Albian		20	Late Albian		1260.12		shale'	35.06006
21	100.13	0		Late Albian		21	Late Albian		1295.18		7li_60sa_33sh	40.329956
22	100.39	0		Late Albian		22	Late Albian		1335.51		5li_10sa_75s...	521.49
23	103.7	0		Middle Albi...		23	Middle Albi...		1857		43sa_57sh	59.140015
24	104.63	0		Middle Albi...		24	Middle Albi...		1916.14		shale'	36.609985
25	105.2	0		Middle Albi...		25	Middle Albi...		1952.75		50sa_50sh'	114.25
26	107	0		M. Albian u/c		26	M. Albian u/c		2067		shale'	0.0
27	111	0		Early Albian		27	Early Albian		2067		54sa_46sh	11.0
28	112	0		Aptian		28	Aptian		2078		8sa_92sh	109.0
29	122	0		Apt/Barr u/c		29	Apt/Barr u/c		2187		shale'	0.0
30	130	0		Late Haute...		30	Late Haute...		2187		9sa_4sh_5ch...	128.1101
31	130.31	0		Late Haute...		31	Late Haute...		2315.11		62sa_38sh	33.839844
32	130.67	0		Late Haute...		32	Late Haute...		2348.95		8li_68sa_24sh	33.05005
33	131	0		intra-Haut ...		33	intra-Haut ...		2382		shale'	0.0
34	132	0		Late Valan...		34	Late Valan...		2382		34_lild_66sh	34.120117
35	132.24	0		Late Valan...		35	Late Valan...		2416.12		85lild_15sh	124.72998
36	133.14	0		Late Valan...		36	Late Valan...		2540.85		9li_26sa_65sh	55.98999
37	133.54	0		Late Valan...		37	Late Valan...		2596.84		sandstone'	47.099854
38	133.87	0		Late Valan...		38	Late Valan...		2643.94		33sa_67sh	114.3501
39	134.69	0		Late Valan...		39	Late Valan...		2758.29		67sa_33sash	56.129883
40	135.09	0		Late Valan...		40	Late Valan...		2814.42		39sa_61sh	270.58008
41	137	0		Berr-Val u/c		41	Berr-Val u/c		3085		shale'	0.0
42	147	0		Late Kimm...		42	Late Kimm...		3085		42sa_58sh	68.0
43	150	0		Late Kimm...		43	Late Kimm...		3153		limestone (lat...	714.0
44	151	0		Oxfordian t...		44	Oxfordian t...		3867		99li_1sh	600.0
45	161.5	0		Callovian M...		45	Callovian M...		4467		52li_48s	53.0
46	163	0		Bajocian to...		46	Bajocian to...		4520		limestone (lat...	215.0
47	171.6	0		Jurassic		47	Top Mohican		4735		limestone (lat...	70.0
48	175.6	0		Jurassic TD		48	Jurassic TD		4805		shale'	30.0
49	176.1	0		Jurassic		49	Jurassic		4835		dolostone (lat...	135.0
50	195	0		Jurassic		50	L. Jur SR		4970		shale'	10.0
51	200	0		Triassic		51	Triassic		4980		conglomerate	320.0
52	225			Basement					5300			

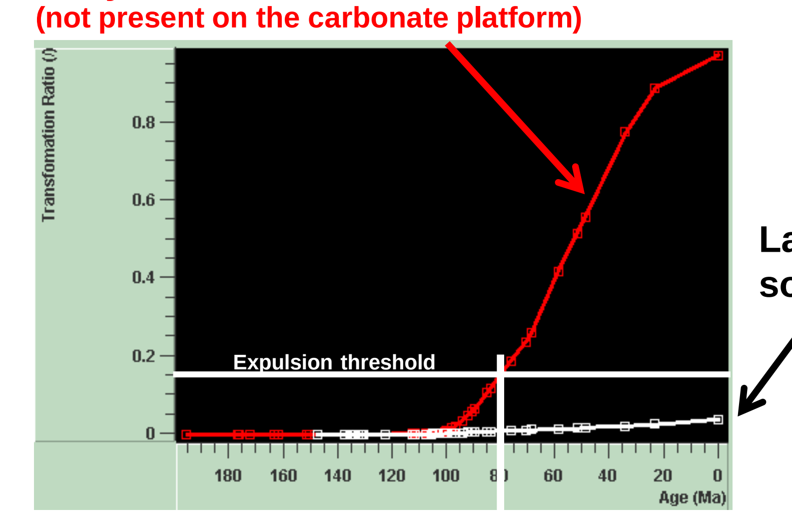
Figure 6: Stratigraphy and lithology (simplified)



#	Start - Ma	End - Ma	Crust geometric thinning: Defined by	Crust geometric thinning: Thickness (m) Before	Crust geometric thinning: Thickness (m) After	Crust geometric thinning: B factors	Upper mantle thermal thinning: Behaviour	Upper mantle thermal thinning: B factors	Lithology update (from end to start): Upper crust	Lithology update (from end to start): Lower crust	Lithology update (from end to start): Upper mantle
1	225.0	200.0	Thickness	38000.0	29000.0	1.3103448	Homogeneous	1.3103448	uppercont...	lowerconti...	mantle

Figure 10: Burial history and maturity (Vitrinite Reflectance) and Rifting events Table

Early Jurassic source rock
(not present on the carbonate platform)



Late Jurassic source rock

80Ma

Figure 11: Transformation ratio history for the various source rocks accounted for and expulsion time

South Griffin J-13

Horizons / Geometry at Present Day

#	Age	Intermediat...	Unconf	Name	Depth (m)
1	0			Sea Bottom	63.4
2	16.21	0		Oligocene	680
3	33.9	0		Unc	900
4	40.4	0		Eocene	900
5	48.6	0		Paleocene	1410
6	65.5	0		Maastrichti...	1533
7	93.6	0		Cenom-Tur	1885
8	98.6	0		Albian	2037
9	110	0		Aptian	2393.13
10	121	0		Aptian-Albian	2881
11	122	0		Apt/Barr u/c	3132
12	130	0		Intra-Haut	3350
13	137	0		Intra-Haut ...	3496
14	147	0		BCU	4160
15	147.3	0		Tith-Berr	4160
16	147.6	0		Tithonian	4390
17	148	0		Tith-SR	4443
18	150	0		Early-Tith	4463
19	151	0		Malm	4675
20	163	0		Dogger	5065
21	167.7	0		Dogger	5605
22	175.6	0		Lias	6000
23	195	0		Lias SR	9780
24	200	0		Triassic	9800
25	225			Basement	11000

Layers / Geometry at Present Day

#	Name	Eroded (m)	Litho	Thickness (m)
1	Miocen-Pre...		shale'	616.6
2	Oligocene-...		sandstone'	220.0
3	Unconformity		shale'	0.0
4	Middle Eoc...		shale'	510.0
5	Paleocene		shale'	123.0
6	L. Maastric...		34li_66sh	352.0
7	Cenom-Tur		18sa_82sh	152.0
8	Albian		56si_34sa_1...	356.12988
9	Aptian		82sa_18sh	487.87012
10	Naskapi		18sa_82sh	251.0
11	Apt/Barr u/c		41sa_15li_44...	218.0
12	Intra-Haut		41sa_15li_44...	146.0
13	Intra-Haut ...		41sa_15li_44...	664.0
14	BCU		41sa_15li_44...	0.0
15	Tith-Berr		50sa_50sh'	230.0
16	Tithonian		limestone (ea...	53.0
17	Tith-SR		marl'	20.0
18	Early-Tith		87li_13sh	212.0
19	Malm		91li_9sh	390.0
20	Dogger		limestone (ea...	540.0
21	Dogger		34li_66sh_tight	395.0
22	Lias		shale'_tight	3780.0
23	Lias SR		shale'	20.0
24	Triassic		salt'	1200.0

Figure 1: Stratigraphy and lithology (simplified)

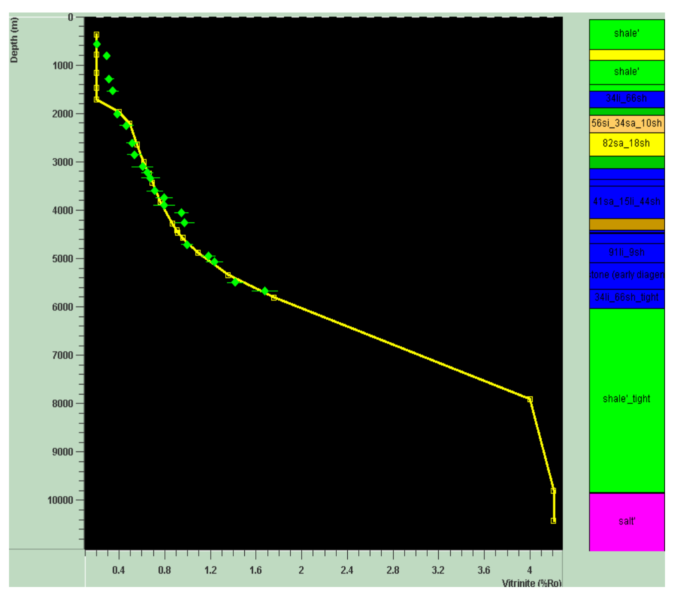


Figure 2: Maturity calibration

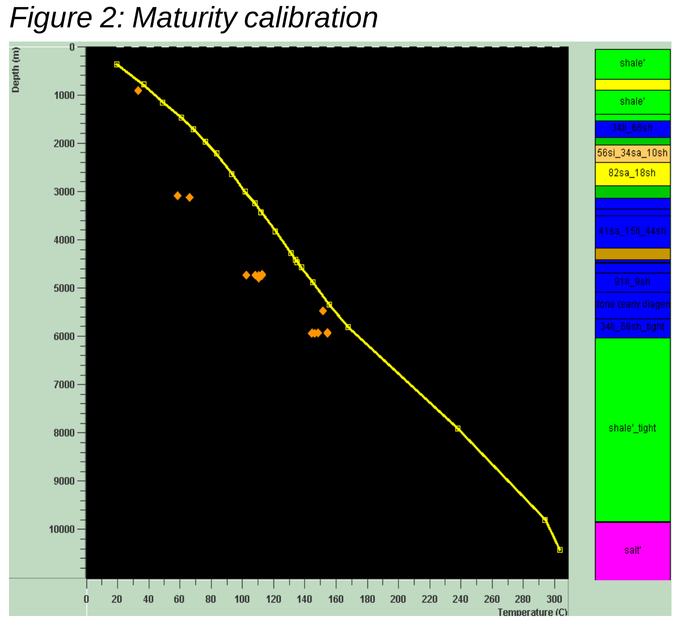


Figure 3: Temperature calibration

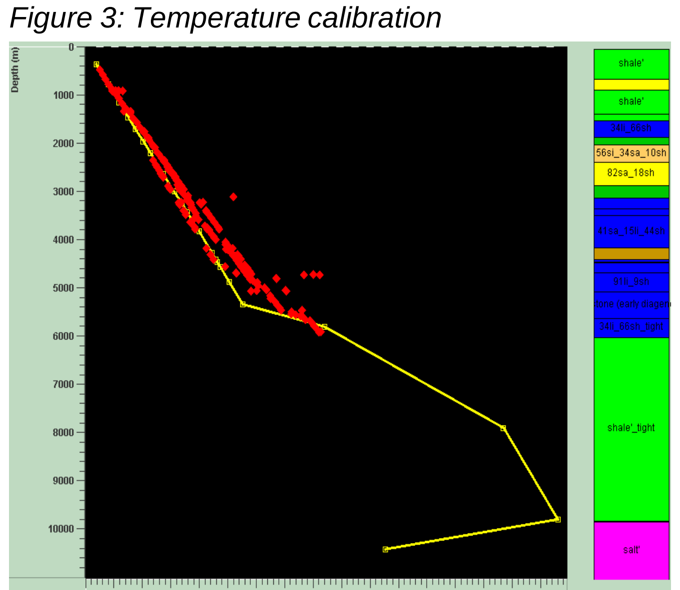
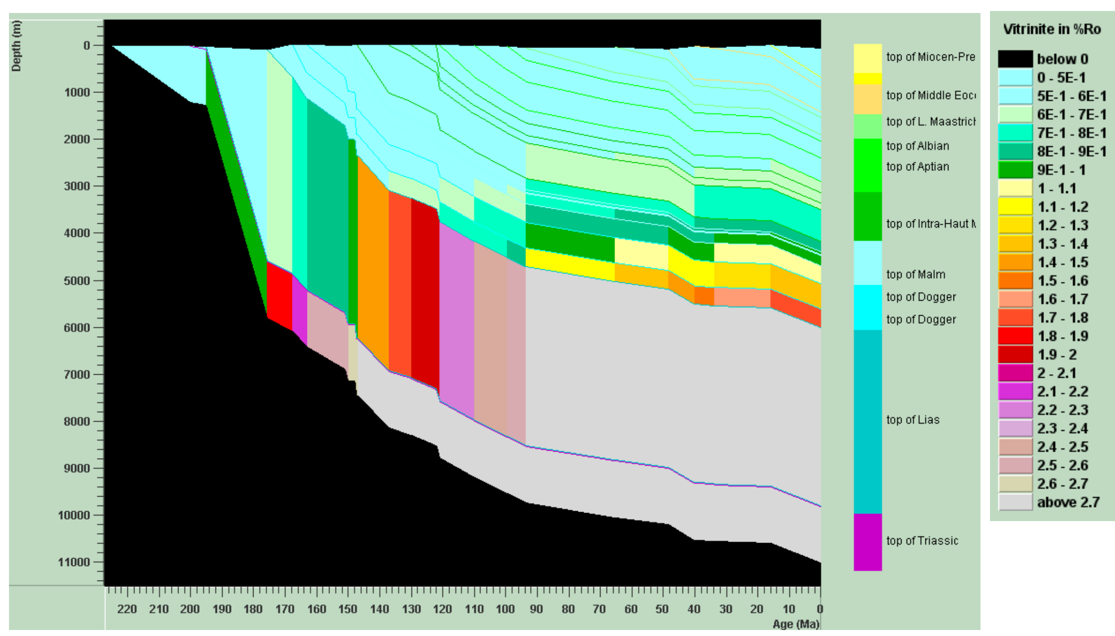


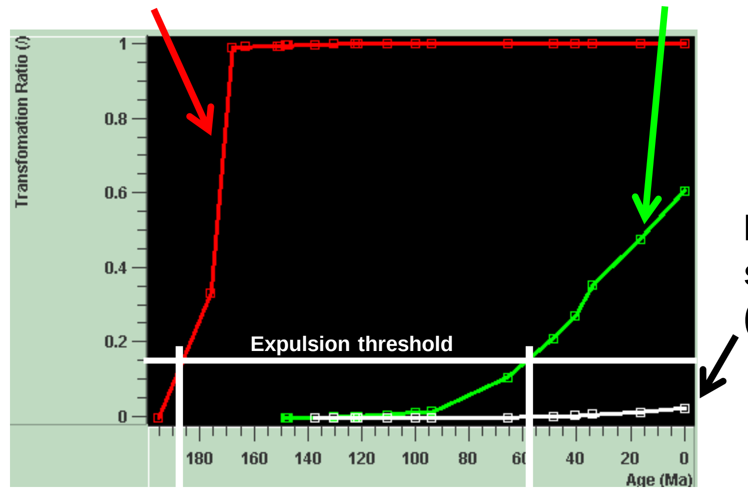
Figure 4: Pressure calibration



#	Start - Ma	End - Ma	Crust geometric thinning: Defined by	Thickness (m): Before	Thickness (m): After	B factors	Upper mantle thermal thinning: Behaviour	B factors	Lithology update (from end to start): Upper crust	Lower crust	Upper mantle
1	225.0	200.0	B factor	35995.0	15650.0	2.3	Homogeneous	2.3	uppercont...	lowerconti...	mantle

Figure 5: Burial history and maturity (Vitrinite Reflectance) and Rifting events Table

Early Jurassic source rock **Late Jurassic source rock**



Lower Cretaceous source rock (Valanginian)

187Ma **67Ma**

Figure 6: Transformation ratio history for the various source rocks accounted for and expulsion time. Only the Early Jurassic and Tithonian source rocks expel hydrocarbons at the South Griffin J-13 location

Hesper P-52

Horizons / Geometry at Present Day

#	Age	Intermediat...	Unconf	Name	Depth (m)
1	0			Sea Bottom	83.7
2	23.03	0		Oligocene ...	879
3	50	0		Montagnai...	1500
4	56	0		Paleocene ...	1540
5	65.5	0		Late Maast...	1635
6	68.5	0		Early Maast...	1645
7	78	0		intra-L. Cre...	1645
8	84	0		Turonian to...	1700
9	89.5	0		Middle to L...	1750
10	94	0		Early Ceno...	1813
11	99.6	0		Albian	1900
12	110	0		Aptian	3218
13	129	0		Late Haute...	3480
14	130	0		Val-Haut	3480
15	144	0		Titho-Berri...	4750
16	146	0		Tithonian SR	5040
17	148	0		Tithonian SS	5070
18	151	0		Jurassic	5110
19	175.6	0		Jurassic	5500
20	192	0		Jurassic SR	6970
21	195	0		Salt	7000
22	200			top basem...	7500

Layers / Geometry at Present Day

#	Name	Eroded (m)	Litho	Thickness (m)
1	Miocene to ...		shale'	795.3
2	Oligocene ...		30sa_70sh'	621.0
3	Montagnai...		chalk'	40.0
4	Paleocene ...		Si50-Sh50	95.0
5	Late Maast...		Si50-Sh50	10.0
6	Early Maast...		chalk'	0.0
7	intra-L. Cre...		chalk'	55.0
8	Turonian to...		chalk'	50.0
9	Middle to L...		chalk'	63.0
10	Early Ceno...		shale'	87.0
11	Albian		5li_25sa_70sh'	1318.0
12	Naskapi		Si50-Sh50	262.0
13	Late Haute...		Si50-Sh50	0.0
14	Val-Haut		7li_27sa_66sh'	1270.0
15	Tithonian-B...		shale_superti...	290.0
16	Tithonian SR		shale_tight'	30.0
17	Tithonian SS		sandstone'	40.0
18	Jurassic		shale_tight'	390.0
19	Jurassic		shale_tight'	1470.0
20	Jurassic SR		shale_tight'	30.0
21	Salt		salt'	500.0

Figure 7: Stratigraphy and lithology (simplified)

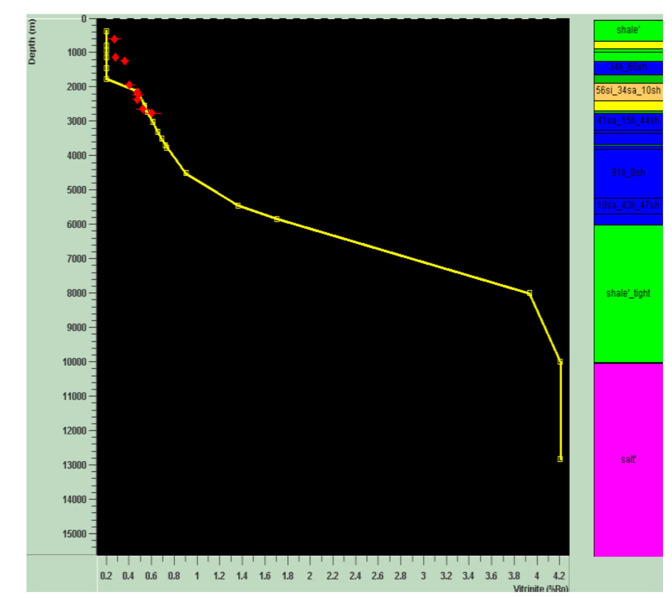


Figure 8: Maturity calibration

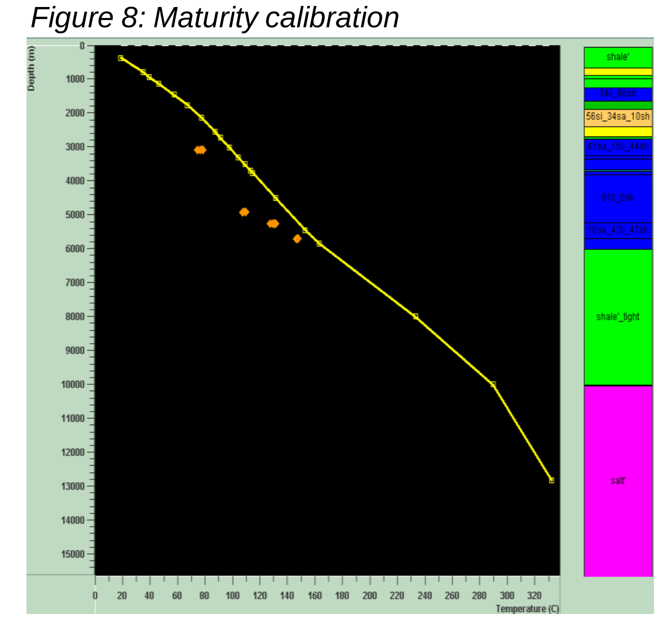


Figure 9: Temperature calibration

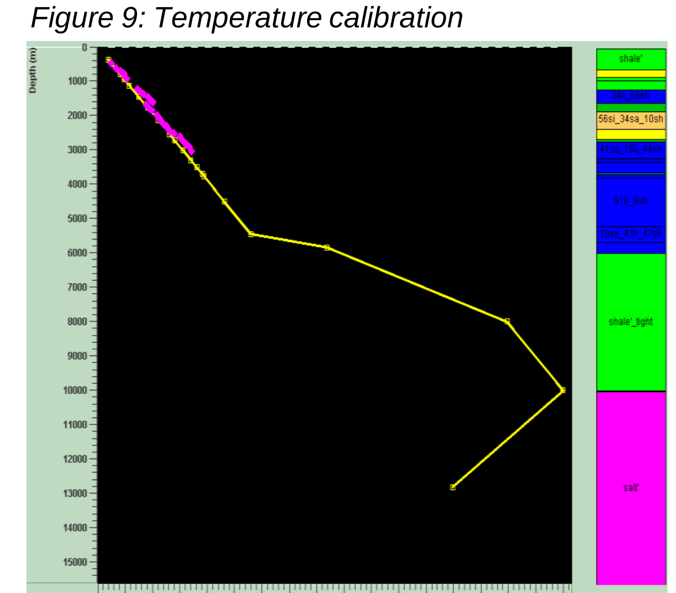
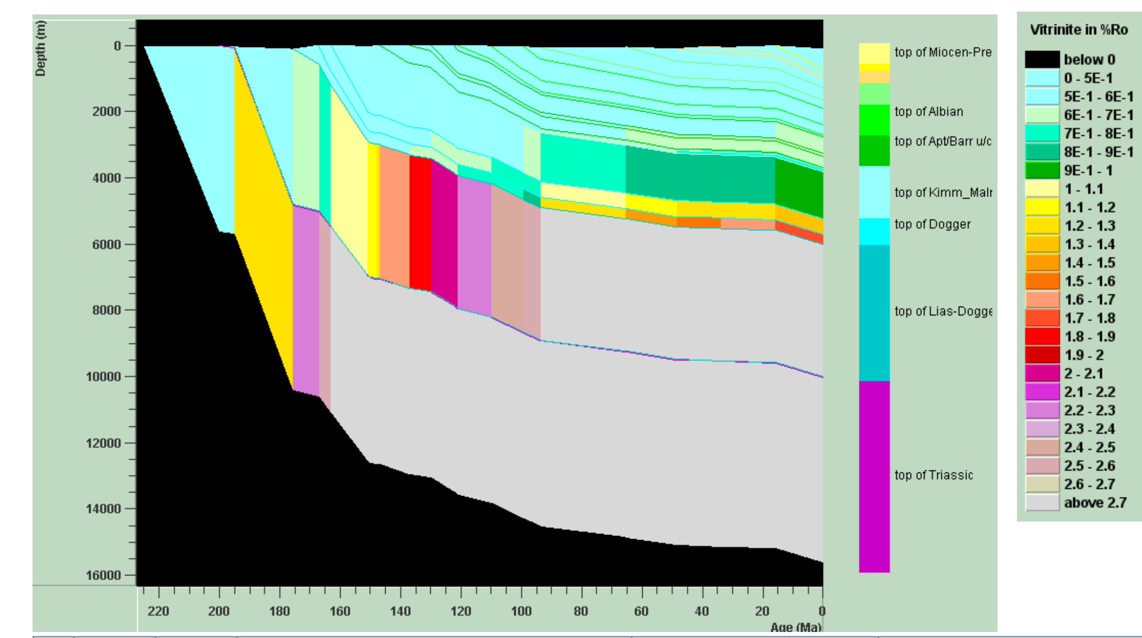


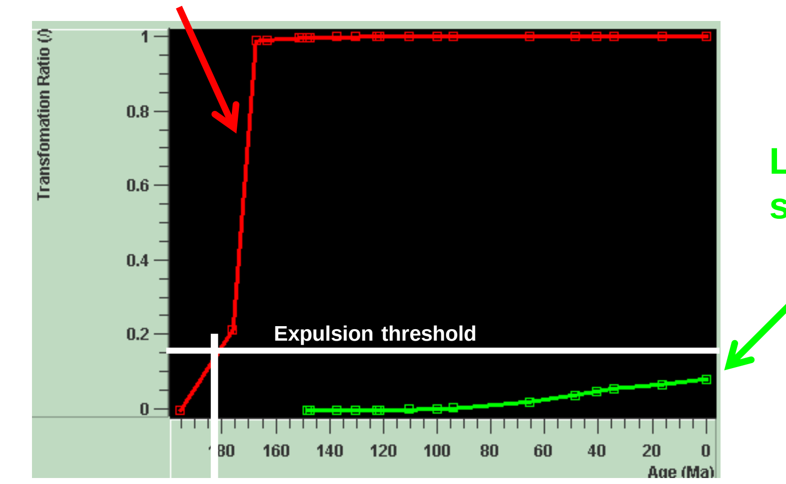
Figure 10: Pressure calibration



#	Start - Ma	End - Ma	Crust geometric thinning: Defined by	Thickness (m): Before	Thickness (m): After	B factors	Upper mantle thermal thinning: Behaviour	B factors	Lithology update (from end to start): Upper crust	Lower crust	Upper mantle
1	225.0	200.0	B factor	35995.0	15650.0	2.3	Homogeneous	2.3	uppercont...	lowerconti...	mantle

Figure 11: Burial history and maturity (Vitrinite Reflectance) and Rifting events Table

Early Jurassic source rock



Late Jurassic source rock

183Ma

Figure 12: Transformation ratio history for the various source rocks accounted for and expulsion time. Only the Early Jurassic source rock expelled hydrocarbons at the Hesper P-52 location and very early (estimated 183 Ma ago)

South Griffin J-13 and Hesper P-52

Glenelg J-48

Horizons

#	Age	Intermediat...	Unconf	Name	Col	Geometry at Present Day: Depth (m)
1	0			Sea Bottom		83.7
2	23.03	0		Oligocene ...		879
3	50	0		Montagnai...		1500
4	56	0		Paleocene ...		1540
5	65.5	0		Late Maast...		1635
6	68.5	0		Early Maast...		1645
7	78	0		intra-L. Cre...		1645
8	84	0		Turonian to...		1700
9	89.5	0		Middle to L...		1750
10	94	0		Early Ceno...		1813
11	99.6	0		Albian		1900
12	110	0		Aptian		3218
13	129	0		Late Haute...		3480
14	130	0		Val-Haut		3480
15	144	0		Titho-Berri...		4750
16	146	0		Tithonian SR		5040
17	148	0		Tithonian SS		5070
18	151	0		Jurassic		5110
19	175.6	0		Jurassic		5500
20	192	0		Jurassic SR		6970
21	195	0		Salt		7000
22	200	0		top basem...		7500

Layers

#	Name	Col	Eroded (m)	Litho	Thickness (m)
1	Miocene to ...			shale'	795.3
2	Oligocene ...			30sa_70sh'	621.0
3	Montagnai...			chalk'	40.0
4	Paleocene ...			Si50-Sh50	95.0
5	Late Maast...			Si50-Sh50	10.0
6	Early Maast...			chalk'	0.0
7	intra-L. Cre...			chalk'	55.0
8	Turonian to...			chalk'	50.0
9	Middle to L...			chalk'	63.0
10	Early Ceno...			shale'	87.0
11	Albian			5li_25sa_70sh'	1318.0
12	Naskapi			Si50-Sh50	262.0
13	Late Haute...			Si50-Sh50	0.0
14	Val-Haut			7li_27sa_66sh'	1270.0
15	Tithonian-B...			shale_superti...	290.0
16	Tithonian SR			shale_tight'	30.0
17	Tithonian SS			sandstone'	40.0
18	Jurassic			shale_tight'	390.0
19	Jurassic			shale_tight'	1470.0
20	Jurassic SR			shale_tight'	30.0
21	Salt			salt'	500.0

Figure 1: Stratigraphy and lithology (simplified)

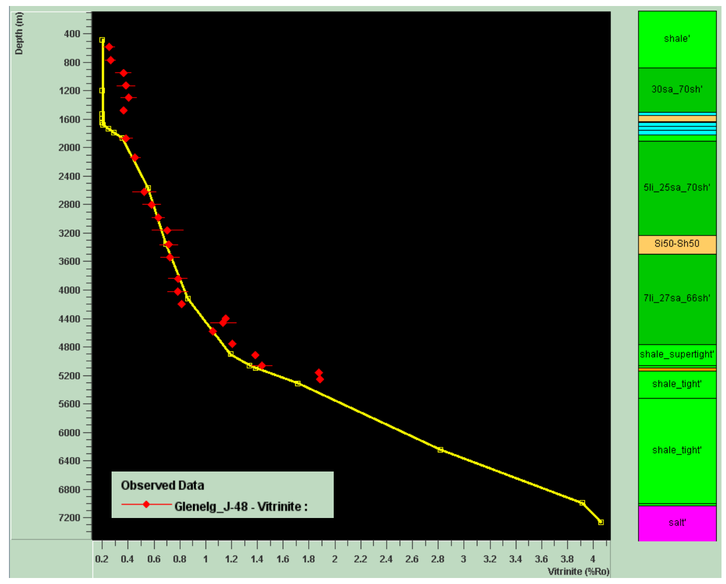


Figure 2: Maturity calibration

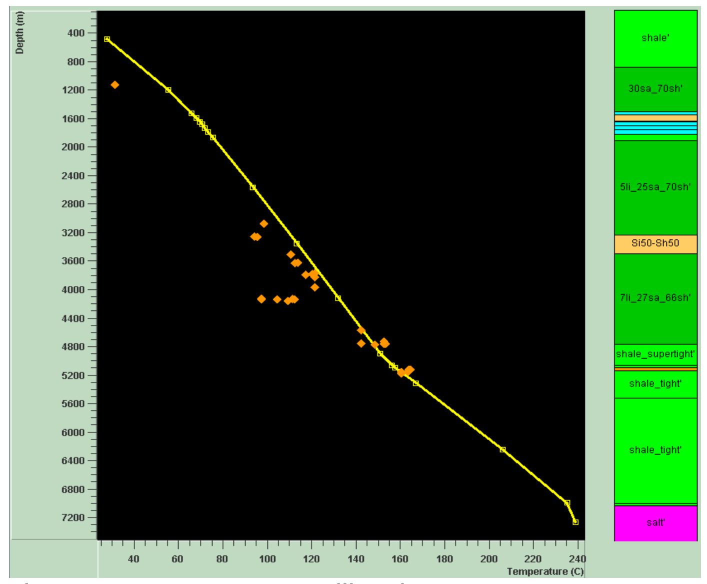


Figure 3: Temperature calibration

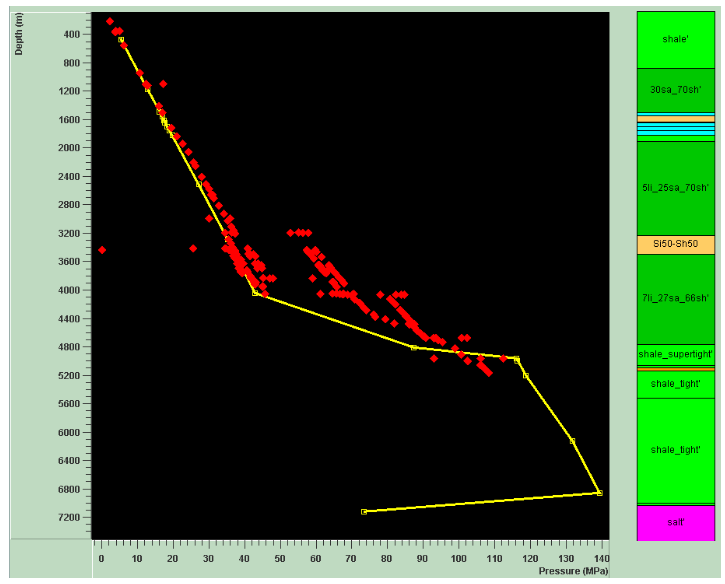
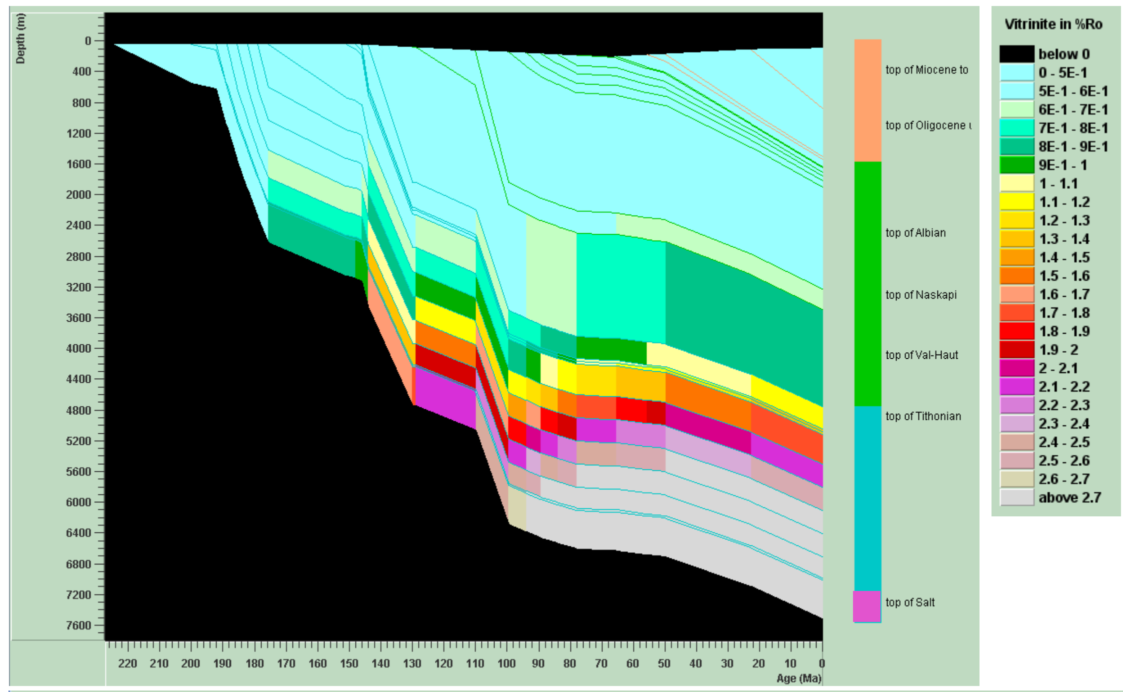


Figure 4: Pressure calibration



#	Start - Ma	End - Ma	Crust evolution: Defined by	Thickness (m): Before	Thickness (m): After	B factors	Upper mantle evolution: Behaviour	B factors	Lithology update (from start to end): Upper crust	Lower crust	Upper mantle
1	225.0	200.0	Thickness	38000.0	24000.0	1.5833334	Homogeneous	1.5833334	uppercont...	lowerconti...	mantle

Figure 5: Burial history and maturity (Vitrinite Reflectance) and Rifting events Table

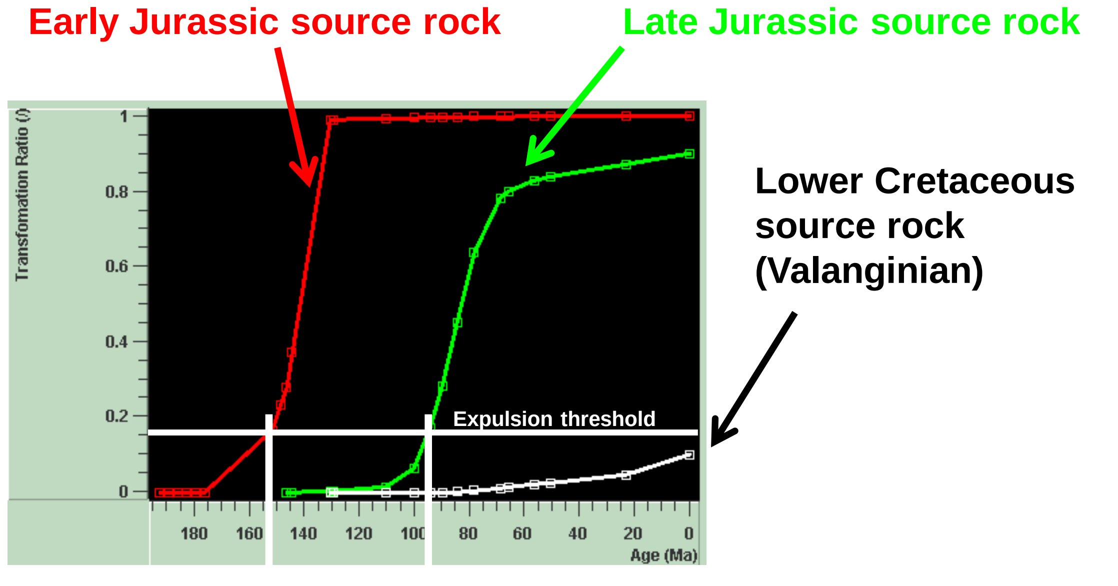


Figure 6: Transformation ratio history for the various source rocks accounted for and expulsion time. Only the Early Jurassic and Tithonian source rocks expel hydrocarbons at the Glenelg J-48 location

Alma F-67

Horizons

#	Age	Intermediat...	Unconf	Name	Col	Geometry at Present Day: Depth (m)
1	0			Sea Bottom		68
2	23.03	0		Oligocene ...		451
3	50	0		Montagnai...		451
4	56	0		Paleocene ...		451
5	65.5	0		Late Maast...		810.5
6	68.9	0		Early Maast...		1188
7	70.6	0		Campanian		1276
8	76	0		intra-L. Cre...		1315
9	84	0		Turonian to...		1315
10	89.5	0		Middle to L...		1440
11	94	0		Early Ceno...		1450
12	99.6	0		Albian		1547
13	101	0		Albian MFS		1775
14	110	0		Aptian		2570
15	114	0		Aptian		2664.0
16	118	0		Aptian MFS		2758.0
17	122	0		Apt/Haut u/c		2852
18	129	0		Late Haute...		2852
19	130.5	0		In Hauterivi...		3730
20	133.75	0		Hauterivian...		4200
21	137	0		Top BCU		4260
22	144	0		Top Tithoni...		4260
23	148	0		Tithonian SR		4780
24	150.8	0		Late Juras...		4800
25	161.2	0		Top Mid-Ju...		4989
26	175.6	0		Jurassic		6828
27	192	0		Jurassic SR		8280
28	195	0		Salt		8300
29	200	0		top basem...		9000

Layers

#	Name	Col	Eroded (m)	Litho	Thickness (m)
1	Miocene to ...			shale	383.0
2	Oligocene ...			shale	0.0
3	Montagnai...			shale	0.0
4	Paleocene ...			shale	359.5
5	Late Maast...			2li_2sa_96sh	377.5
6	Early Maast...			3sa_97sh	88.0
7	Campanian			3chalk_97sh	39.0
8	intra-L. Cre...			shale	0.0
9	Turonian to...			2li_1chalk_88...	125.0
10	Middle to L...			1li_12sa_87sh	10.0
11	Early Ceno...			marl	97.0
12	Albian			50sa_50sh	228.0
13	Albian MFS			shale	795.0
14	Aptian			70sa_30sh	94.0
15	Naskapi			1li_4sa_95sh	94.0
16	Naskapi			shale_mid-tight	94.0
17	Apt/Haut u/c			50sa_50sh	0.0
18	Late Haute...			70sa_30sh	878.0
19	In Hauterivi...			30sa_70sh	470.0
20	Hauterivian...			shale_tight	60.0
21	Top BCU			26li_74sh	0.0
22	Top Tithoni...			7sa_93sh_su...	520.0
23	Tithonian SR			shale_superti...	20.0
24	Late Juras...			9li_91sh	189.0
25	Top Mid-Ju...			6li_9sa_85sh	1839.0
26	Jurassic			6li_9sa_85sh	1452.0
27	Jurassic SR			shale	20.0
28	Salt			salt	700.0

Figure 7: Stratigraphy and lithology (simplified)

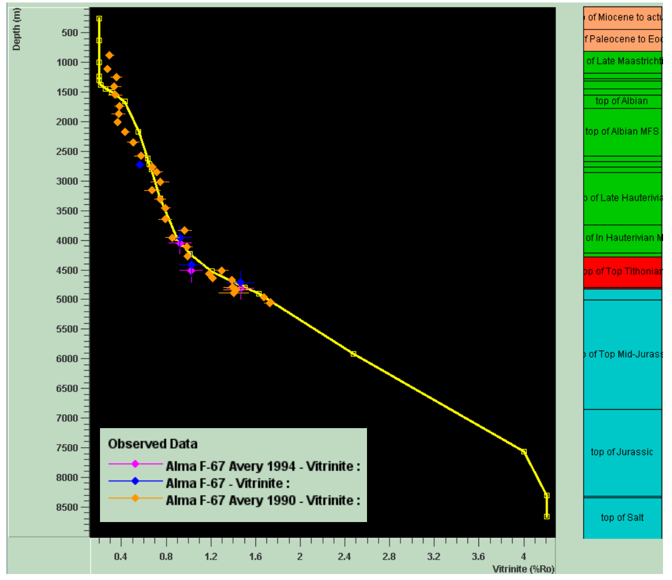


Figure 8: Maturity calibration

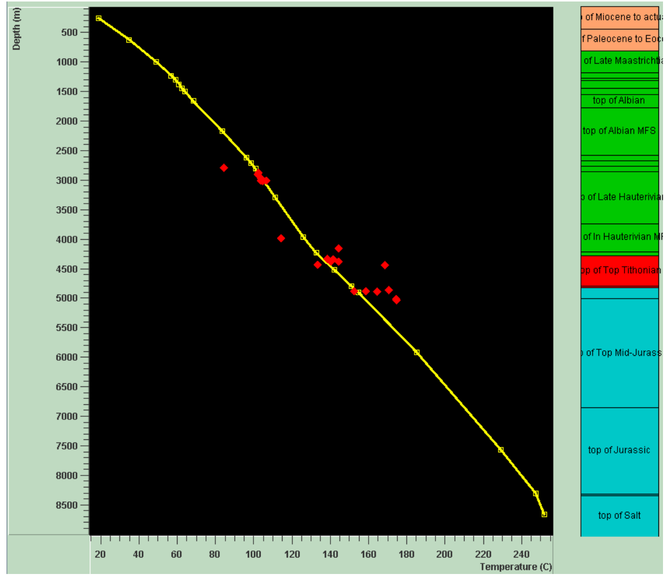


Figure 9: Temperature calibration

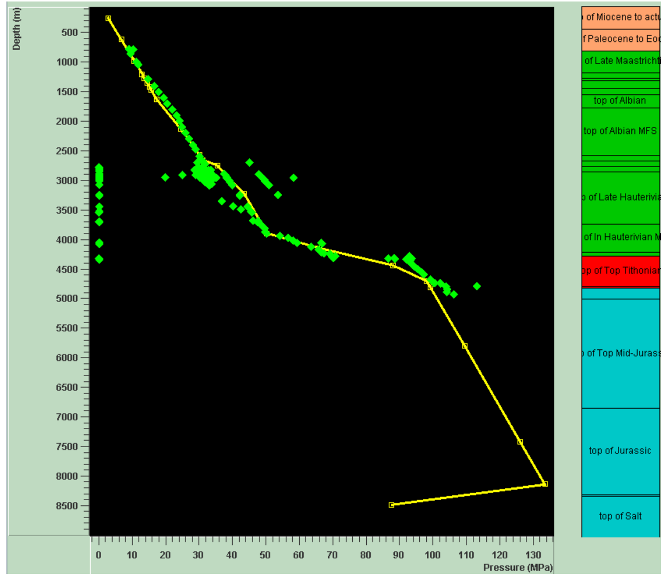
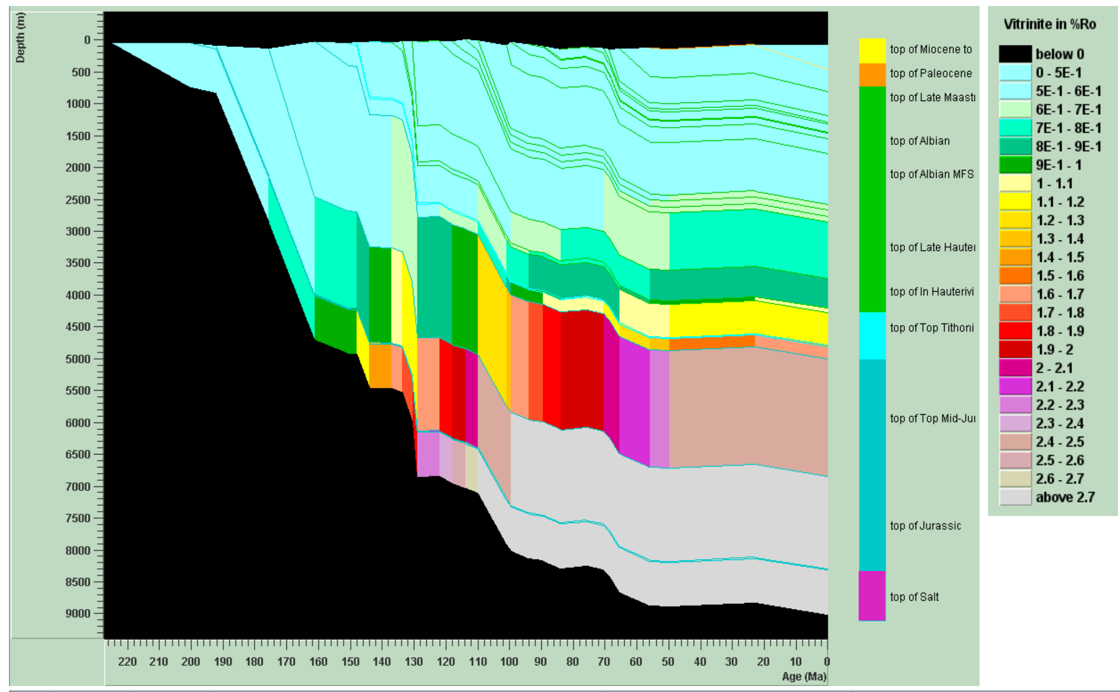


Figure 10: Pressure calibration



#	Start - Ma	End - Ma	Crust geometric thinning: Defined by	Thickness (m): Before	Thickness (m): After	B factors	Upper mantle thermal thinning: Behaviour	B factors	Lithology update (from end to start): Upper crust	Lower crust	Upper mantle
1	225.0	200.0	Thickness	38000.0	24000.0	1.5833334	Homogeneous	1.5833334	uppercont...	lowerconti...	mantle

Figure 11: Burial history and maturity (Vitrinite Reflectance) and Rifting events Table

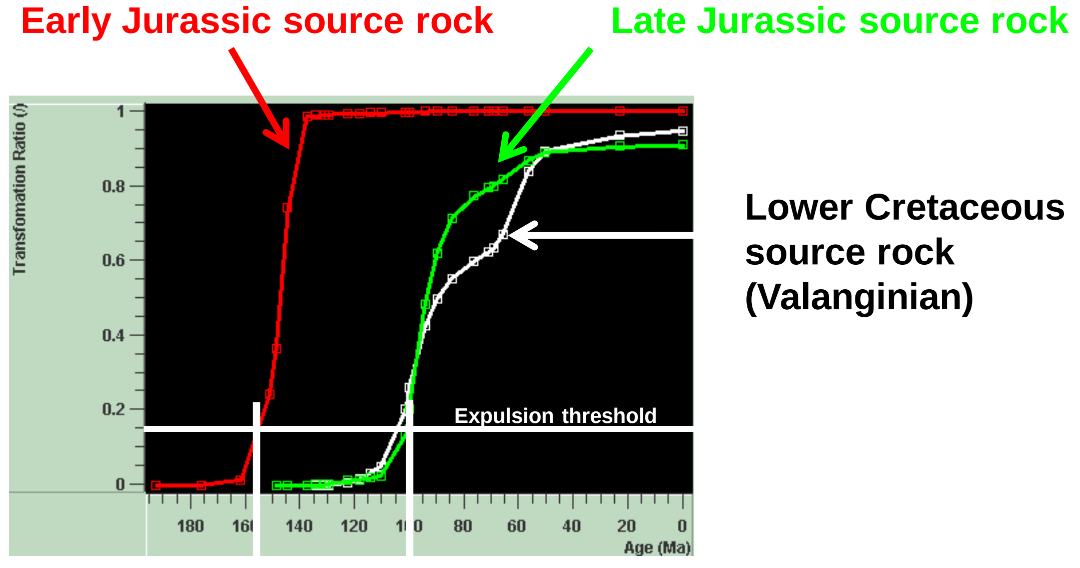


Figure 12: Transformation ratio history for the various source rocks accounted for and expulsion time. The Early Jurassic, Tithonian and Valanginian source rocks expel hydrocarbons at the Alma F-67. The Aptian (Naskapi) source rock is only incipiently mature (see Figure 11, above) for having expelled hydrocarbons

Shelburne G-29

Horizons

#	Age	Unconf	Name	Depth (m)
1	0		Sea Bottom	1153.5
2	4.5		Late Mioce...	1600
3	6.8		Late Mioce...	1826
4	7.3		Late Mioce...	1875
5	10.1		Late Mioce...	2150
6	10.5		Late Mioce...	2184
7	11.61		L. Miocene ...	2294
8	36		Eocene	2294
9	56		Paleocene	2583.5
10	60.2		Paleocene	2645
11	65.5		Maastrichti...	2718.5
12	69.2		Maastrichti...	2844
13	70		Maastrichti...	2872
14	70.6		Cenomanian	2893
15	71.3		Cenomanian	2909
16	72		Cenomanian	2925
17	76		intra-L. Cre...	3022.5
18	85		Santonian-...	3022.5
19	85.5		Santonian-...	3033
20	86		Santonian-...	3059
21	87		Santonian-...	3074
22	89.5		Turonian	3087
23	94		Cenomanian	3544
24	96		Cenomanian	3617
25	96.4		Cenomanian	3628
26	99.6		Cenomani...	3725.5
27	128		Hauterivian...	3725.5
28	133		BCU	3800
29	144		Tith-Berria...	3800
30	147.5		Tithonian	3980
31	151		Jurassic	4000
32	175		Jurassic	4400
33	183		Jurassic	4700
34	185		Early Jur	5080
35	200		Triassic	5100
36	225		top basem...	5750

Layers

#	Intermediat...	Name	Eroded (m)	Litho	Thickness (m)
1	0	Late Mioce...		shale'_cpy_m...	446.5
2	0	Late Mioce...		10sa_90sh	226.0
3	0	Late Mioce...		sandstone'	49.0
4	0	Late Mioce...		shale'	275.0
5	0	Late Mioce...		sandstone'	34.0
6	0	Late Mioce...		shale'	110.0
7	0	L. Miocene ...		shale'	0.0
8	0	Eocene		shale'	289.5
9	0	Paleocene		97li_3sh	61.5
10	0	Paleocene		shale'	73.5
11	0	Maastrichti...		Claystone	125.5
12	0	Maastrichti...		limestone (lat...	28.0
13	0	Maastrichti...		Claystone	21.0
14	0	Late Camp...		Claystone	16.0
15	0	Late Camp...		limestone (lat...	16.0
16	0	Late Camp...		Claystone	97.5
17	0	intra-L. Cre...		Claystone	0.0
18	0	Santonian-...		limestone (lat...	10.5
19	0	Santonian-...		Claystone	26.0
20	0	Santonian-...		limestone (lat...	15.0
21	0	Santonian-...		shale'	13.0
22	0	Turonian		shale_mid-tig...	457.0
23	0	Cenomanian		Silty-shale	73.0
24	0	Cenomanian		sandstone'	11.0
25	0	Cenomanian		Silty-shale	97.5
26	0	Cenomani...		Silty-shale	0.0
27	0	Hauterivian...		Silty-shale	74.5
28	0	BCU		Silty-shale	0.0
29	0	Tith-Berria...		Silty-shale	180.0
30	0	Tithonian		shale'	20.0
31	0	Kimmeridg...		Marly-limesto...	400.0
32	0	Jurassic		shale'	300.0
33	0	Jurassic		shale'	380.0
34	0	Early Jur		shale'	20.0
35	0	Triassic		salt'	650.0

Figure 1: Stratigraphy and lithology (simplified)

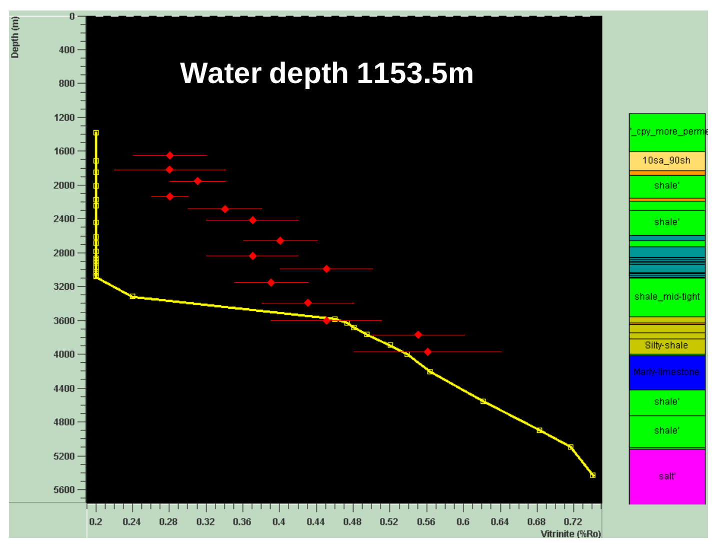


Figure 2: Maturity calibration

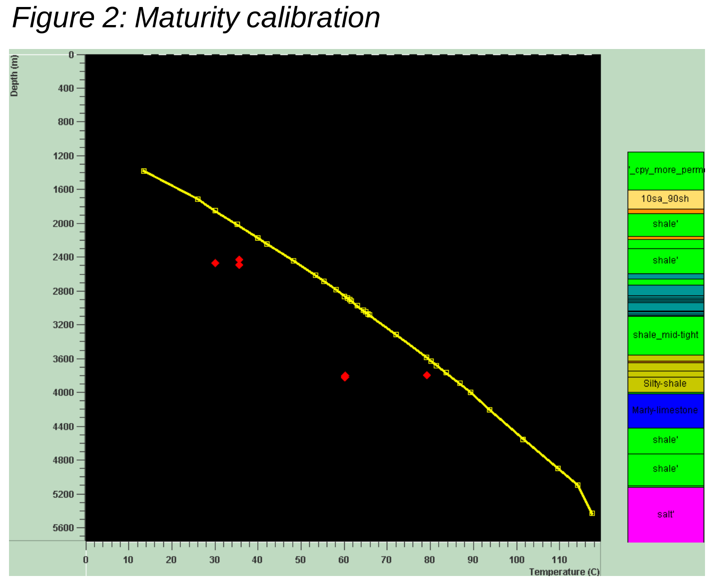


Figure 3: Temperature calibration

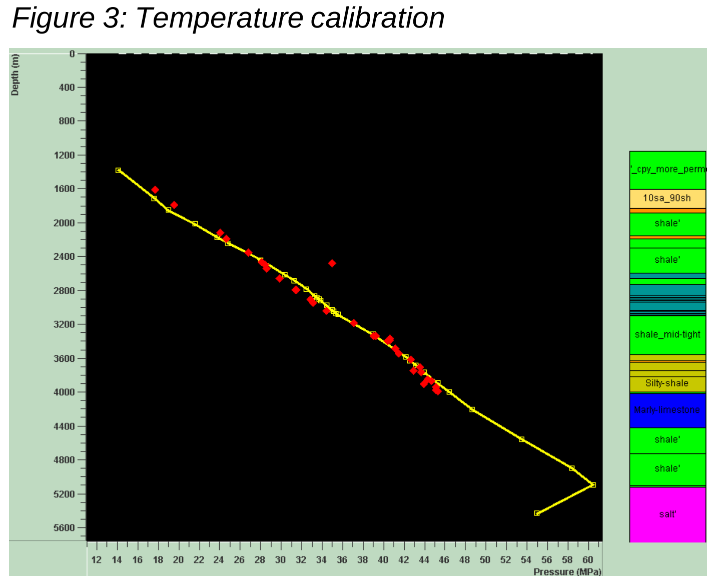
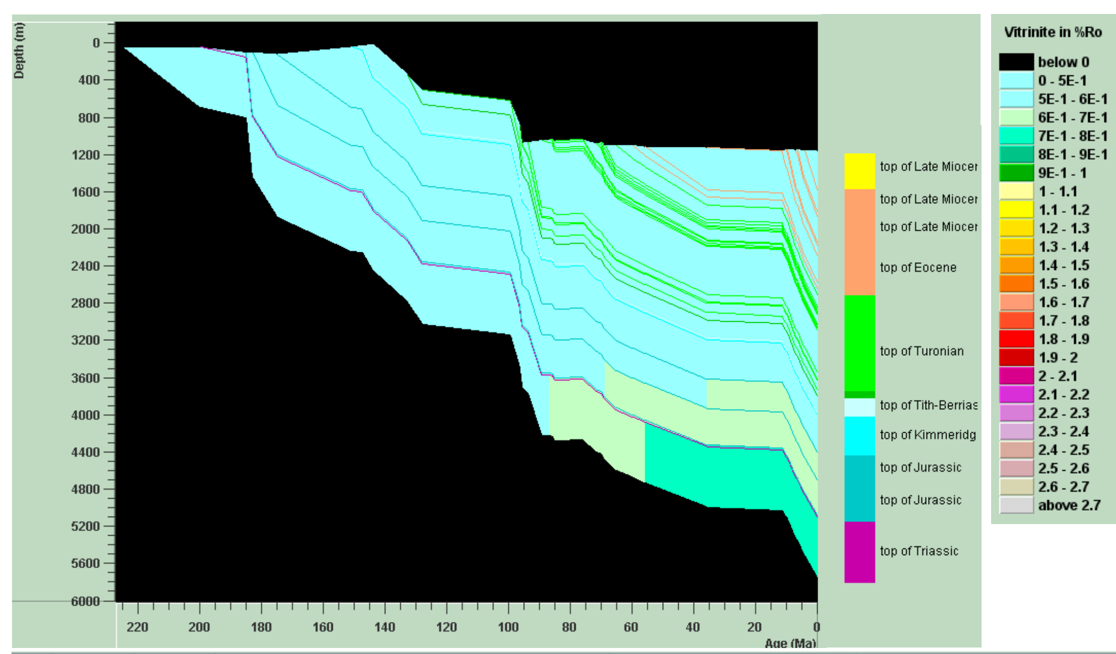


Figure 4: Pressure calibration



#	Start - Ma	End - Ma	Crust geometric thinning: Defined by	Thickness (m): Before	Thickness (m): After	B factors	Upper mantle thermal thinning: Behaviour	B factors	Lithology update (from end to start): Upper crust	Lower crust	Upper mantle
1	225.0	200.0	Thickness	38000.0	26000.0	1.4615384	Homogeneous	1.4615384	uppercont...	lowerconti...	mantle

Figure 5: Burial history and maturity (Vitrinite Reflectance) and Rifting events Table

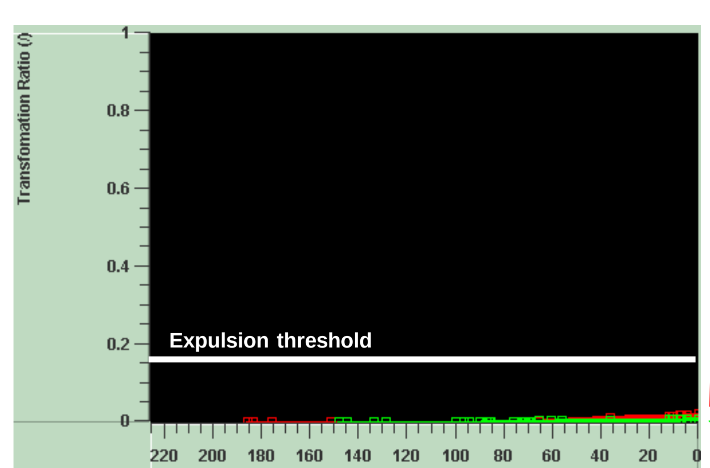


Figure 6: Transformation ratio history for the various source rocks accounted for and expulsion time. None of the source rocks are mature enough for having expelled any hydrocarbons

Shubenacadie H-100

Horizons

#	Age	Unconf	Name	Depth (m)
1	0		Sea Bottom	1500.9
2	5.33		toplayer2	1869.3884
3	7.25		u/c (Tortoni...	2002.1272
4	11.6		Early to Mid...	2302.8635
5	23		Oligocene ...	3091
6	35		Eocene	3091
7	41.3		Eocene	3156.1
8	43.2		Eocene	3179.1
9	50.5		Eocene	3290.9
10	56		Paleocene	3356
11	65.5		Maastrichti...	3492
12	69.1		Maastrichti...	3573.2
13	69.8		Maastrichti...	3592.6
14	70.6		Turonian to...	3642
15	74		Late Camp...	3670
16	76		Turonian to...	3750
17	80.5		Intra Cret u/c	3750
18	84		Santonian ...	3840
19	94		Cenomanian	3993
20	99.6		Cretaceous	4200
21	114.9		Valang-Ha...	4800
22	118.425		Valang-Ha...	4975.0
23	121.95		Valang-Ha...	5150.0
24	125.475		Valang-Ha...	5325.0
25	129		Valang-Ha...	5500
26	137		BCU	5750
27	147		Tithonian	5750
28	150.8		Jurassic	5800
29	175		Jurassic	6000
30	183		Pliensb SR	6300
31	186		Pliensbach...	6330
32	189		Jurassic	6500
33	200		Triassic	6550
34	225		top basem...	7000

Layers

#	Intermediat...	Name	Eroded (m)	Litho	Thickness (m)
1	0	Late Mioce...		shale'	368.4884
2	0	Late Mioce...		30sa_70sh'	132.73877
3	0	u/c (Tortoni...		shale'	300.73633
4	0	Early to Mid...		11si_89shcp	788.1365
5	0	Oligocene ...		shale'_cpy	0.0
6	0	Eocene		shale'_cpy	65.1001
7	0	Eocene		chalk'	23.0
8	0	Eocene		3ch_97shcp	111.799805
9	0	Eocene		chalk'	65.1001
10	0	Paleocene		7ch_93shcp	136.0
11	0	Maastrichti...		shale-tighter	81.19995
12	0	Maastrichti...		chalk'	19.400146
13	0	Maastrichti...		shale'_cpy	49.399902
14	0	Turonian to...		shale'_cpy	28.0
15	0	Late Camp...		chalk'	80.0
16	0	Turonian to...		shale'_cpy	0.0
17	0	Intra Cret u/c		chalk'	90.0
18	0	Santonian ...		shale'_cpy	153.0
19	0	Cenomanian		shale'_cpy	207.0
20	0	Cretaceous		shale'_cpy	600.0
21	0	Valang-Ha...		shale'_cpy	175.0
22	0	Valang-Ha...		shale'_cpy	175.0
23	0	Valang-Ha...		shale'_cpy	175.0
24	0	Valang-Ha...		shale'_cpy	175.0
25	0	Valang-Ha...		marl'	250.0
26	0	BCU		shale'_cpy	0.0
27	0	Tithonian		shale'_cpy	50.0
28	0	Jurassic		shale'_cpy	200.0
29	0	Toarcian		shale'_cpy	300.0
30	0	Pliensb SR		shale'_cpy	30.0
31	0	Pliensbach...		shale'_cpy	170.0
32	0	Sinemurian		shale'_cpy	50.0
33	0	Triassic		salt'	450.0

Figure 7: Stratigraphy and lithology (simplified)

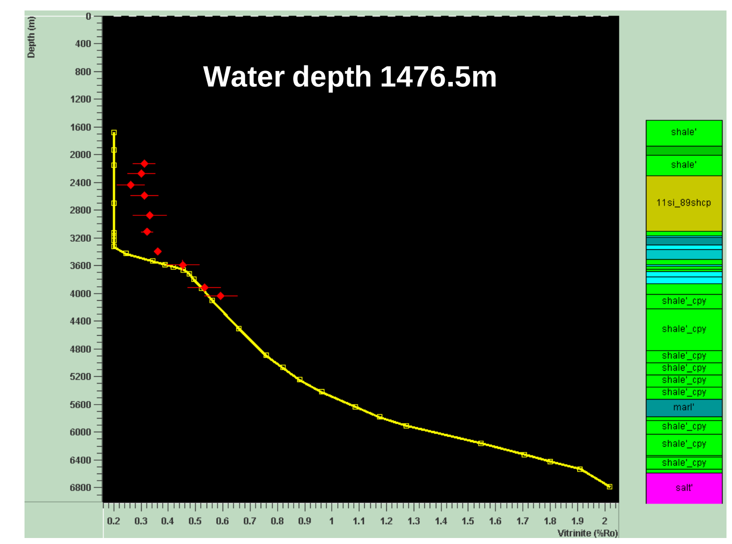


Figure 8: Maturity calibration

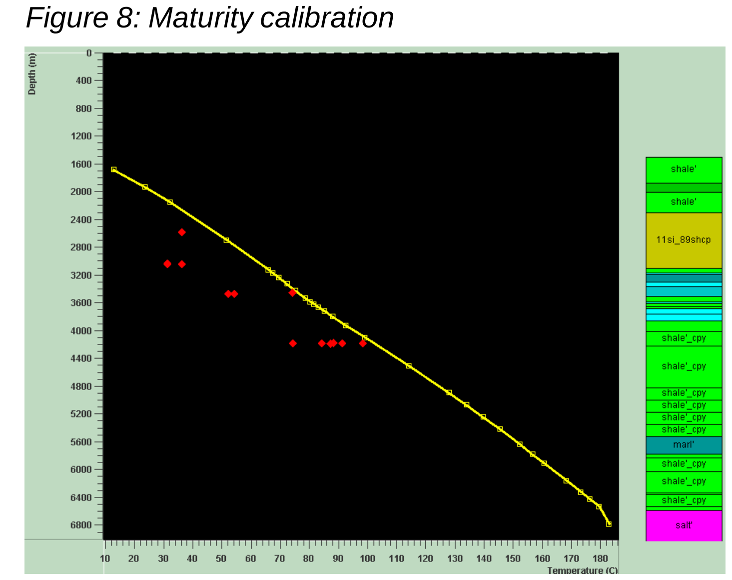


Figure 9: Temperature calibration

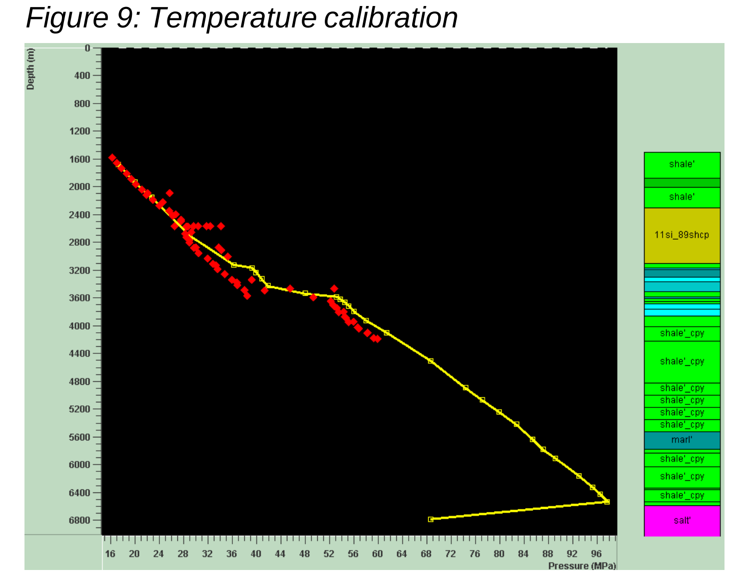
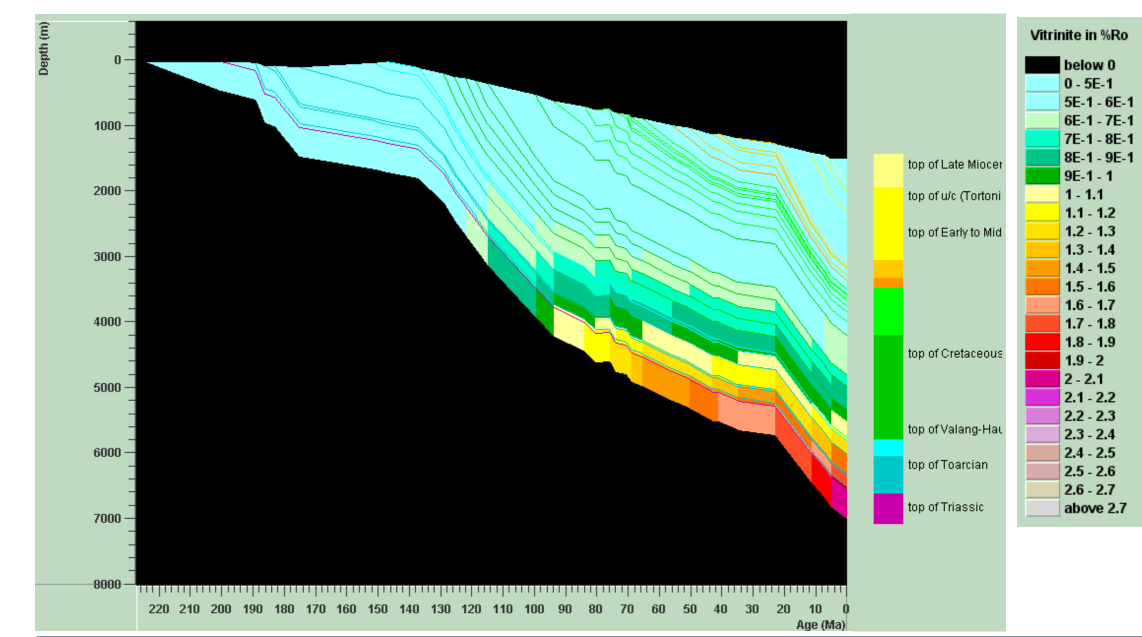


Figure 10: Pressure calibration



#	Start - Ma	End - Ma	Crust geometric thinning: Defined by	Thickness (m): Before	Thickness (m): After	B factors	Upper mantle thermal thinning: Behaviour	B factors	Lithology update (from end to start): Upper crust	Lower crust	Upper mantle
1	225.0	200.0	Thickness	38000.0	24000.0	1.5833334	Homogeneous	1.5833334	uppercont...	lowerconti...	mantle

Figure 11: Burial history and maturity (Vitrinite Reflectance) and Rifting events Table

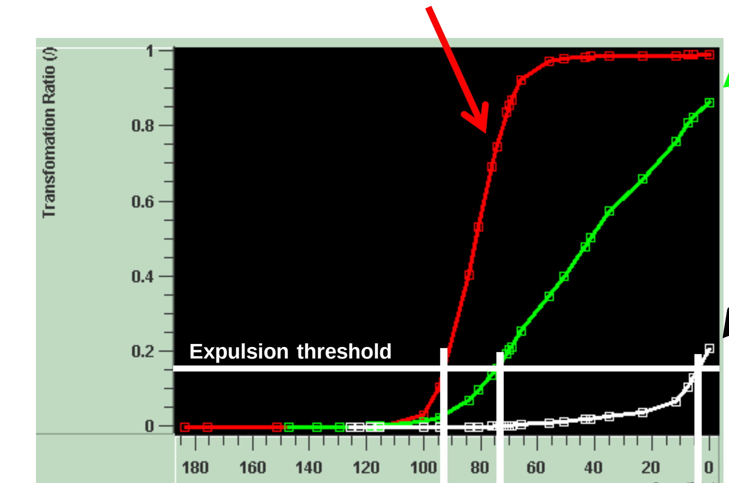


Figure 12: Transformation ratio history for the various source rocks accounted for and expulsion time. The Early Jurassic and Tithonian source rocks expel hydrocarbons at the Shubenacadie H-100 location. Expulsion from the Valanginian source rock is recent and incipient only

Shelburne G-29 and Shubenacadie H-100

Balvenie B-79

Horizons

#	Age	Intermediat...	Unconf	Name	Depth (m)
13	81.97	0		Turonian to...	3694.83
14	88.83	0		Turonian to...	3756.75
15	93.6	0		Cenomanian	3799.9
16	99.6	0		Albian	4109.87
17	100.36	0		Albian	4223.43
18	100.38	0		Albian	4226.69
19	100.47	0		Albian	4240.38
20	100.49	0		Albian	4243.64
21	100.72	0		Albian	4277.86
22	100.77	0		Albian	4286
23	101.18	0		Albian	4347.27
24	101.2	0		Albian	4349.23
25	101.32	0		Albian	4367.48
26	101.35	0		Albian	4372.36
27	102.18	0		Albian	4497.5
28	102.24	0		Albian	4505.65
29	103.7	0		Cretaceous	4724.76
30	112.775	0		Cretaceous	5562.3794
31	117.3125	0		Cretaceous	5981.19
32	121.85	0		Cretaceous	6400
33	126.3875	0		Cretaceous	6450
34	130.925	0		Cretaceous	7028.49
35	135.4625	0		Cretaceous	7606.9814
36	137	0		Cretaceous	7803
37	145.5	0		Tithonian	8803
38	150	0		Jurassic	8850
39	183	0		Pliens SR	10420
40	195	0		Jurassic	10460
40	195	0		Jurassic	10460
41	200	0		Triassic	11803
42	225	0		top basem...	12803

Layers / Geometry at Present Day

#	Name	Eroded (m)	Litho	Thickness (m)
12	Turonian to...		limestone (lat...	21.180176
13	Turonian to...		shale'	61.91992
14	Turonian to...		92do_8sh	43.149902
15	Cenomanian		5do_95sh	309.9702
16	Albian		shale'	113.56006
17	Albian		sandstone'	3.2597656
18	Albian		shale'	13.689941
19	Albian		sandstone'	3.260254
20	Albian		shale'	34.219727
21	Albian		sandstone'	8.140137
22	Albian		shale'	61.27002
23	Albian		sandstone'	1.9599609
24	Albian		shale'	18.25
25	Albian		sandstone'	4.879883
26	Albian		shale'	125.14014
27	Albian		sandstone'	8.149902
28	Albian		shale'	219.10986
29	Cretaceous		shale'	837.6196
30	Cretaceous		shale'	418.81055
31	Cretaceous		shale'	418.81006
32	Cretaceous		shale'	50.0
33	Cretaceous		shale'	578.49023
34	Cretaceous		shale'	578.4912
35	Cretaceous		shale'	196.01855
36	Cretaceous		salt'	1000.0
37	Tithonian		shale'	47.0
38	Jurassic		shale'	1570.0
39	Pliens SR		shale'	40.0
39	Pliens SR		shale'	40.0
40	Jurassic		shale'	1343.0
41	Triassic		salt'	1000.0

Figure 1: Stratigraphy and lithology (simplified)

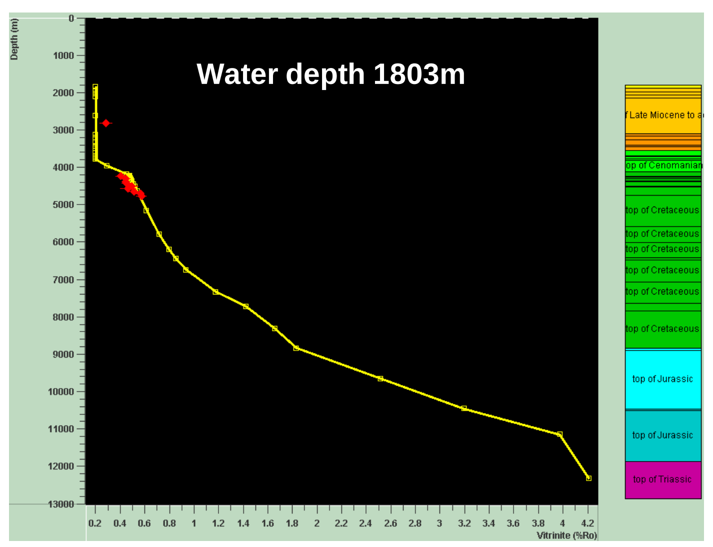


Figure 2: Maturity calibration

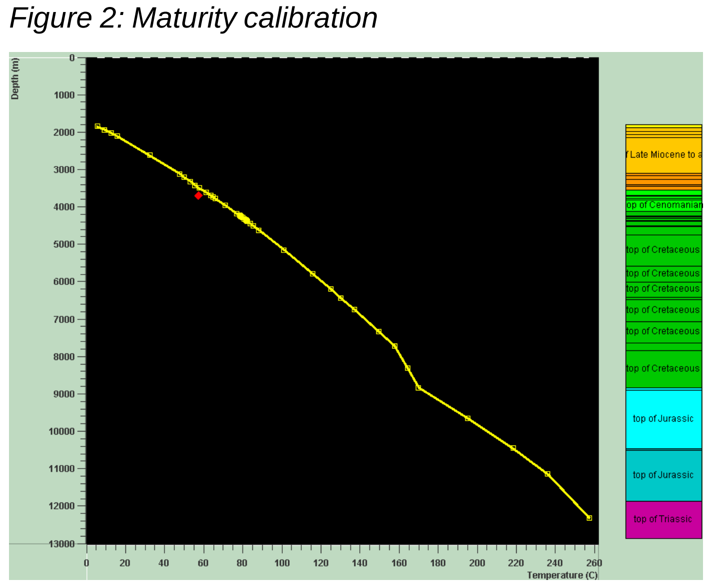


Figure 3: Temperature calibration

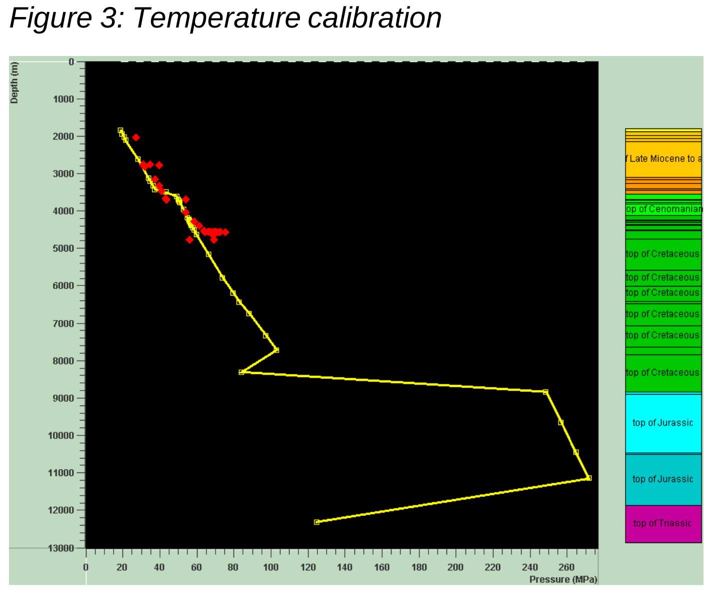
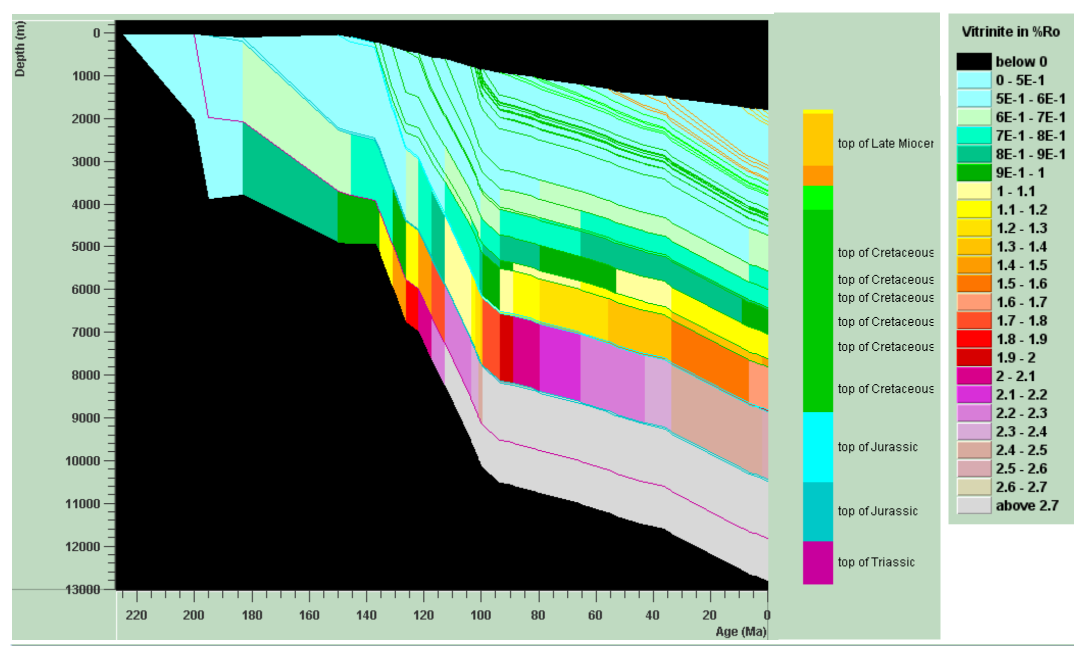


Figure 4: Pressure calibration



#	Start - Ma	End - Ma	Crust geometric thinning: Defined by	Thickness (m): Before	Thickness (m): After	B factors	Upper mantle thermal thinning: Behaviour	B factors	Lithology update (from end to start): Upper crust	Lower crust	Upper mantle
1	225.0	183.0	B factor	36000.0	16000.0	2.25	Homogeneous	2.25	uppercont...	lowerconti...	mantle

Figure 5: Burial history and maturity (Vitrinite Reflectance) and Rifting events Table

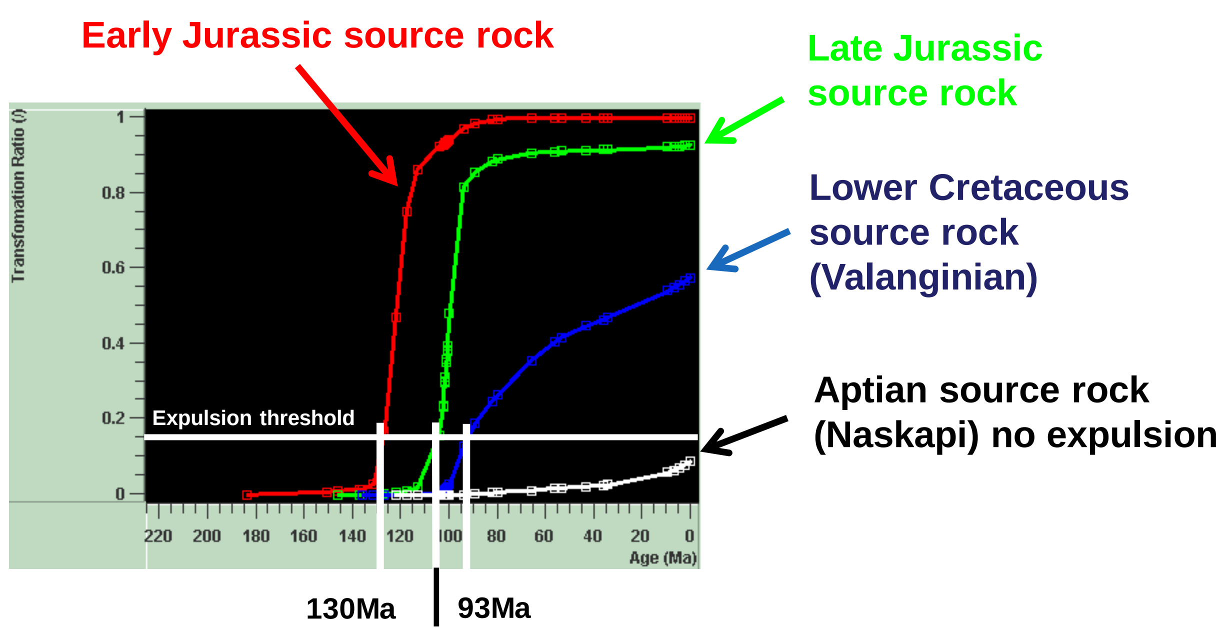


Figure 6: Transformation ratio history for the various source rocks accounted for and expulsion time. The Early Jurassic, Tithonian and Valanginian source rocks expel hydrocarbons at the Balvenie B-79 location. The Aptian (Naskapi) source rock did not expel hydrocarbons

Crimson F-81

Horizons

#	Age	Intermediat...	Unconf	Name	Depth (m)
1	0			Sea Bottom	2091.5
2	49.5	0		Early to Mid...	3386
3	49.75	0		Eocene	3462
4	50	0		Early to Mid...	3520
5	56	0		Paleocene	3520
6	62	0		Paleocene	3560
7	68	0		Ter/Cret Bo...	3596
8	91	0		intra-Cret u/c	3596
9	94	0		Late Ceno...	3655
10	96.8	0		Cenomanian	3720
11	99.6	0		Late Albian	3882
12	110	0		Aptian	4548
13	121	0		Early Apt	4722
14	122	0		Apt/Barr u/c	4772
15	128	0		Hauterivian...	4772
16	130.5	0		Hauterivian...	5928
17	131.25	0		Hauterivian	6420
18	131.625	0		Hauterivian	6430
19	132	0		Hauterivian...	6676
20	140	0		Cretaceous	7962
21	145.5	0		Tithonian SR	7962
22	151	0		Jurassic	8040
23	175	0		Jurassic	11000
24	187.5	0		E. Jur SR	13980
25	200	0		Triassic	14000
26	225			top basem...	15000

Layers / Geometry at Present Day

#	Name	Eroded (m)	Litho	Thickness (m)
1	Miocene to ...		shale'	1294.5
2	Early to Mid...		shale'_cpy	76.0
3	Eocene		85li_15sh	58.0
4	Early to Mid...		85li_15sh	0.0
5	Paleocene		11li_89sh	40.0
6	Paleocene		85li_15sh	36.0
7	Ter/Cret Bo...		shale'_cpy	0.0
8	intra-Cret u/c		85li_15sh	59.0
9	Late Ceno...		marl'	65.0
10	Cenomanian		8si_92shcp	162.0
11	Late Albian		8si_92shcp	666.0
12	Aptian		2li_4si_94shcp	174.0
13	Early Apt		2li_4si_94shcp	50.0
14	Apt/Barr u/c		shale'_cpy	0.0
15	Hauterivian...		6sa_94shcp	1156.0
16	Hauterivian...		6sa_94shcp	492.0
17	Sand		sandstone'	10.0
18	Hauterivian		shale'_cpy	246.0
19	Hauterivian...		shale'_cpy	1286.0
20	Cretaceous		salt'	0.0
21	Tithonian SR		shale'_cpy	78.0
22	Jurassic		shale'_cpy	2960.0
23	Jurassic		shale'_cpy	2980.0
24	E. Jur SR		shale'	20.0
25	Jurassic		salt'	1000.0

Figure 7: Stratigraphy and lithology (simplified)

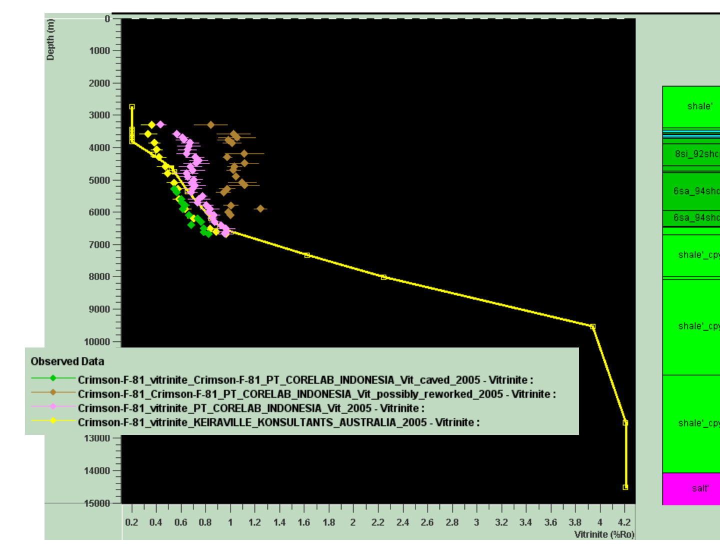


Figure 8: Maturity calibration

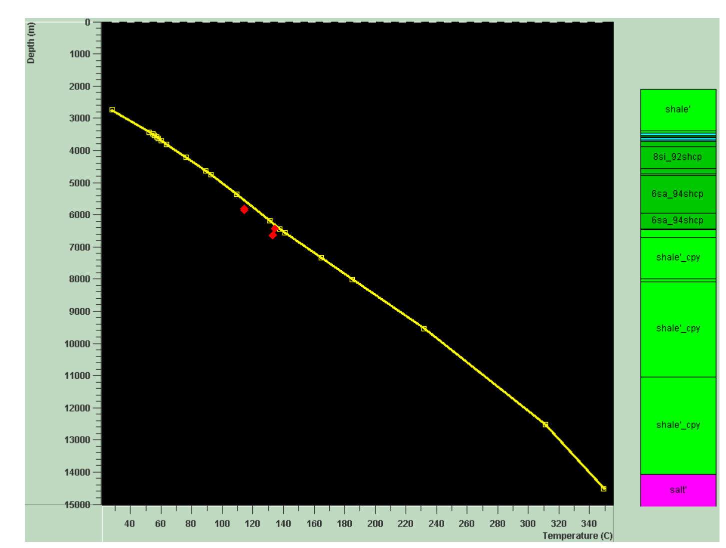


Figure 9: Temperature calibration

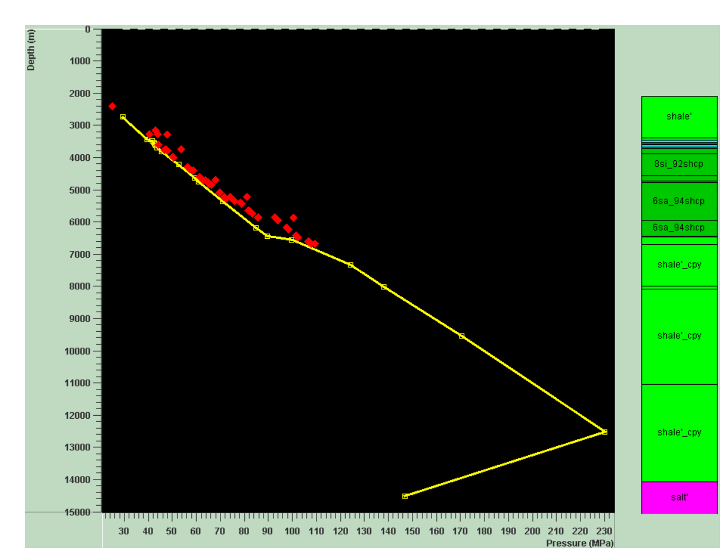
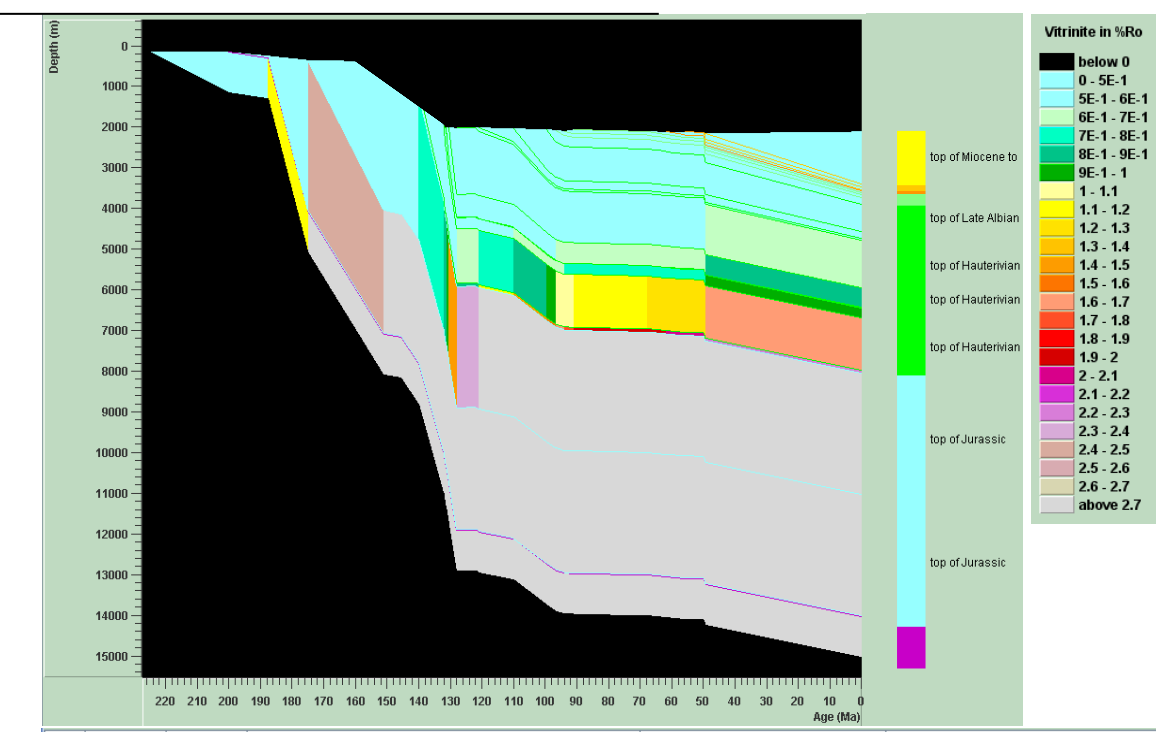


Figure 10: Pressure calibration



#	Start - Ma	End - Ma	Crust geometric thinning: Defined by	Thickness (m): Before	Thickness (m): After	B factors	Upper mantle thermal thinning: Behaviour	B factors	Lithology update (from end to start): Upper crust	Lower crust	Upper mantle
1	225.0	200.0	B factor	35980.0	7000.0	5.14	Homogeneous	5.14	uppercont...	lowerconti...	mantle

Figure 11: Burial history and maturity (Vitrinite Reflectance) and rifting events Table

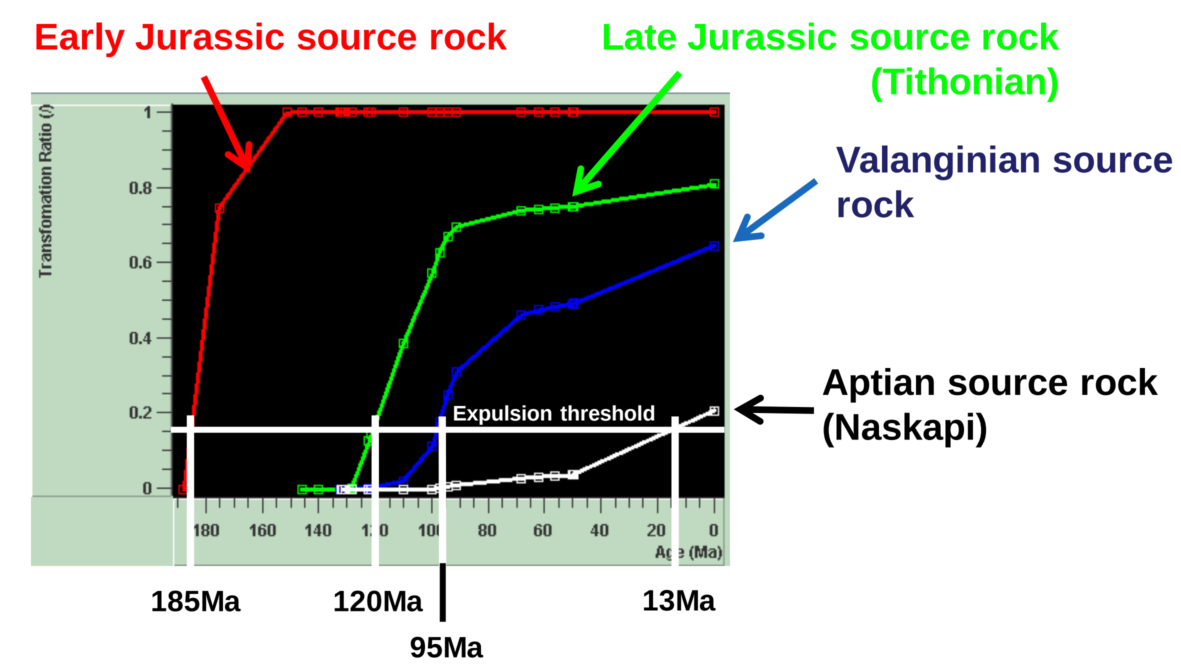


Figure 12: Transformation ratio history for the various source rocks accounted for and expulsion time. All source rocks expel at the Crimson F-81 location. Expulsion from the Aptian (Naskapi) source rock is recent and incipient only

Tantallon M-41

Horizons / Geometry at Present Day

#	Age	Unconf	Name	Col	Depth (m)
1	0		Sea Bottom		1516
2	2.58		Mio-Plio-Pl...		2270
3	30		Paleo-Olig...		2525
4	65.5		Late Camp...		3124
5	93.6		Cenomanian		3263
6	95		Late Albian		3314
7	99.9		Late Albian		3366
8	102.6		Late Albian		3585
9	107.8		Early Albian		3678
10	108.4		Early Albian		3690
11	108.6		Early Albian		3711
12	108.9		Early Albian		3744
13	110		Early Albian		4100
14	112		Aptian		4122
15	122		Haute- Barr...		4400
16	136.2		Valanginian		5143
17	136.6		Val-SR		5550
18	137		Berriasian		5600
19	145.5		Tithonian		6363.569
20	150.8		Jurassic		7153.038
21	183		Early J-SR		10013
22	195		Jurassic		10033
23	200		Triassic		11170
24	225		top basem...		11500

Layers / Geometry at Present Day

Intermediat...	#	Name	Col	Eroded (m)	Litho	Thickness (m)
0	1	Pleistocene			shale'_cpy	754.0
0	2	Pliocene to...			shale'_cpy	255.0
0	3	Paleo-Olig...			shale'_cpy	599.0
0	4	Late Camp...			limestone (lat...	139.0
0	5	Cenomanian			limestone (lat...	51.0
0	6	Late Albian			60li_40cl	52.0
0	7	Late Albian			3li_97shcp	219.0
0	8	Late Albian			silt	93.0
0	9	Early Albian			shale'_cpy	12.0
0	10	Early Albian			silt	21.0
0	11	Early Albian			shale'_cpy	33.0
0	12	Early Albian			silt	356.0
0	13	Early Albian			shale'_cpy	22.0
0	14	Aptian			3li_3sa_94sh...	278.0
0	15	Hauter-Bar...			shale'_cpy	743.0
0	16	Valanginian			sandstone'	407.0
0	17	Val-SR			shale'	50.0
0	18	Berriasian			1si_2sa_97s...	763.56885
0	19	Tithonian			shale'_cpy_cpy	789.46924
0	20	Jurassic			shale'_cpy_cpy	2859.962
0	21	Early J-SR			shale'	20.0
0	22	Jurassic			shale'_cpy_cpy	1137.0
0	23	Triassic			salt'	330.0

Figure 1: Stratigraphy and lithology (simplified)

Summary and Conclusions

1D modeling applied early in the project, before developing 2D and 3D models confirms that:

- The evolution of the petroleum system(s) - burial and maturity evolution driven by the rifting thermal events based on the lithosphere changes derived from the OETR 2009 and SMART lines, present day thickness of the various layers defined in age and depth – is consistent with observations on Temperature, Maturity and Pressure.
- The evolution of the petroleum system does not requires rapid burial before hypothetical erosions of significant thicknesses at any of the unconformities for the models to be calibrated.

As a consequence, burial and sedimentation rates follow a positive evolution with minor erosion phases from rift end to present day. Unconformities correspond essentially to hiatuses (non-deposition, sediment bypass area) or limited erosion surfaces (less than 300 m eroded)

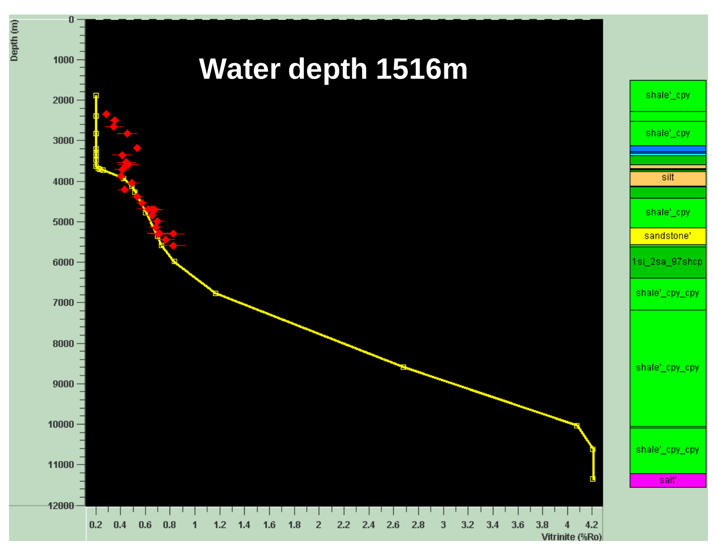


Figure 2: Maturity calibration

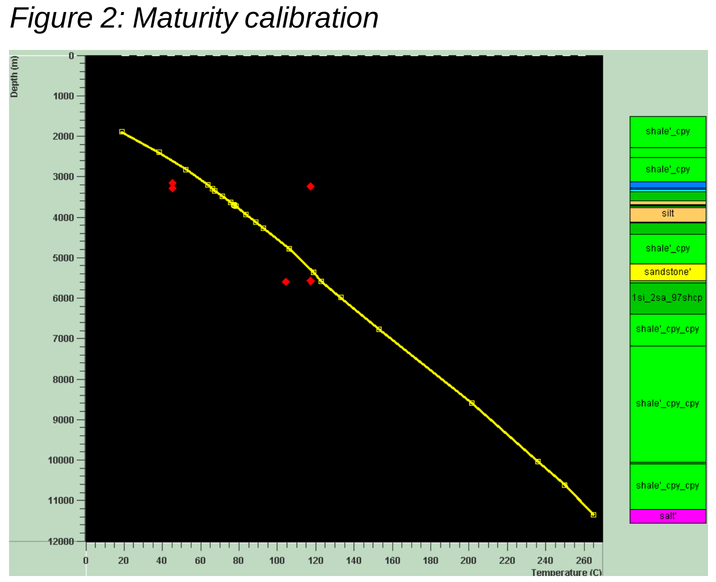


Figure 3: Temperature calibration

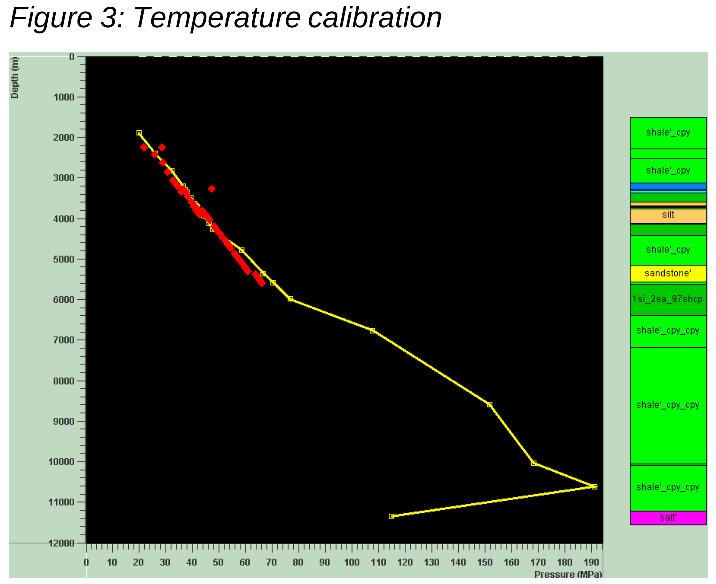
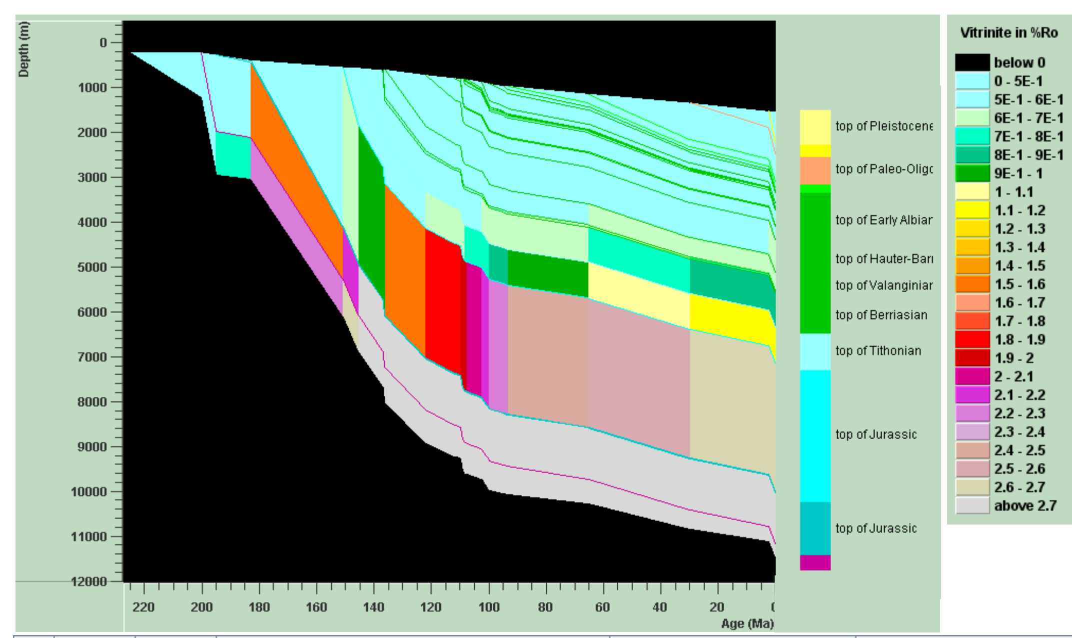


Figure 4: Pressure calibration



#	Start - Ma	End - Ma	Crust geometric thinning: Defined by	Crust geometric thinning: Thickness (m) Before	Crust geometric thinning: Thickness (m) After	Crust geometric thinning: B factors	Upper mantle thermal thinning: Behaviour	Upper mantle thermal thinning: B factors	Lithology update (from end to start): Upper crust	Lithology update (from end to start): Lower crust	Lithology update (from end to start): Upper mantle
1	225.0	200.0	B factor	36000.0	9000.0	4.0	Homogeneous	4.0	uppercont...	lowerconti...	mantle

Figure 5: Burial history and maturity (Vitrinite Reflectance) and Rifting events Table

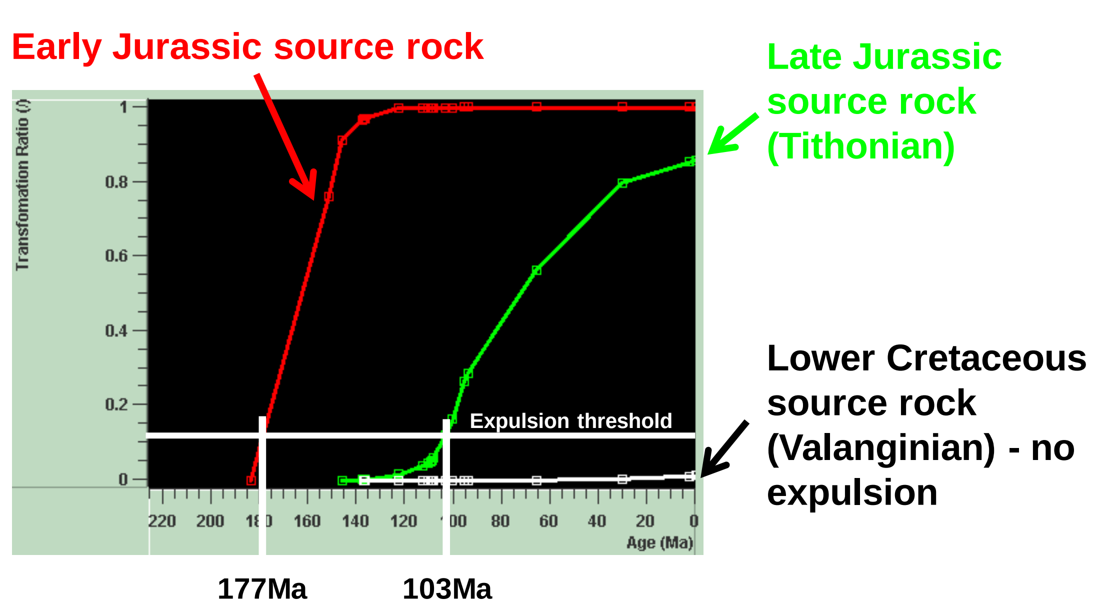


Figure 6: Transformation ratio history for the various source rocks accounted for and expulsion time. The Early Jurassic, Tithonian source rocks expel hydrocarbons at the Tantallon M-41 location. The Valanginian and Aptian (Naskapi) source rocksare not mature enough to have expelled hydrocarbons

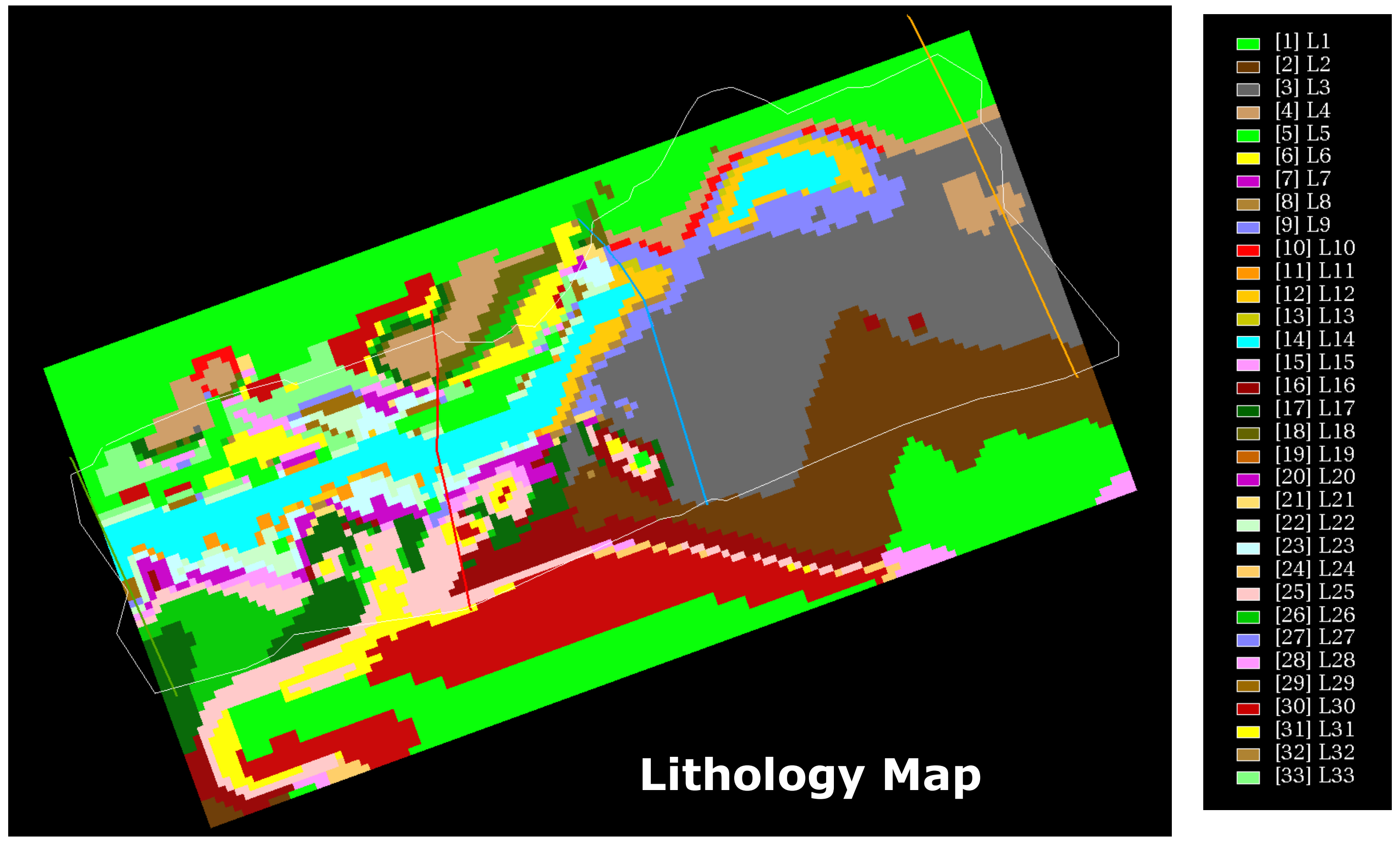
CHAPTER 7-2

BASIN MODELING – TEMIS 2D

7-2-1

2D Modeling Introduction

BASIN MODELING – TEMIS 2D

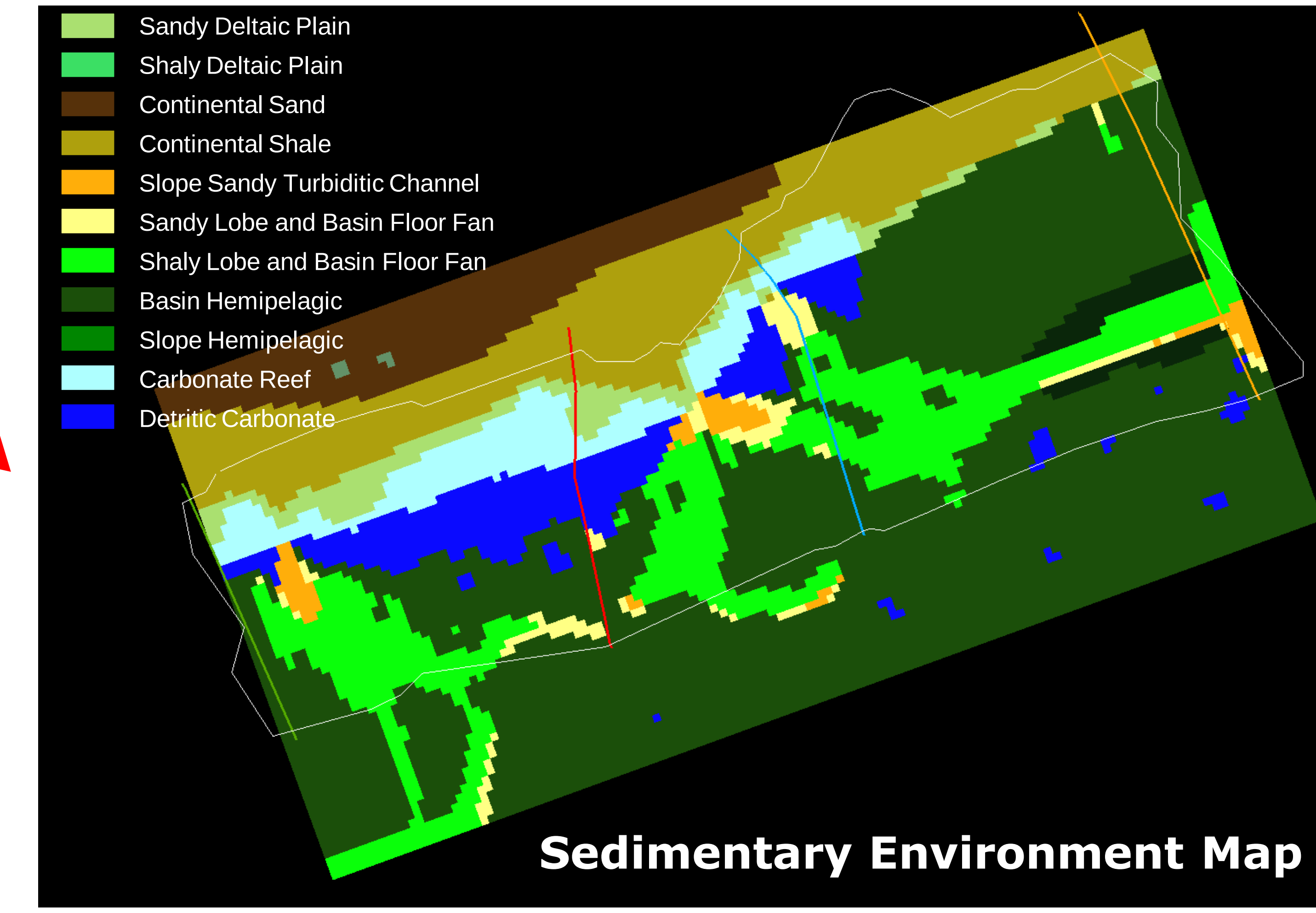


Dionisos® Modeling

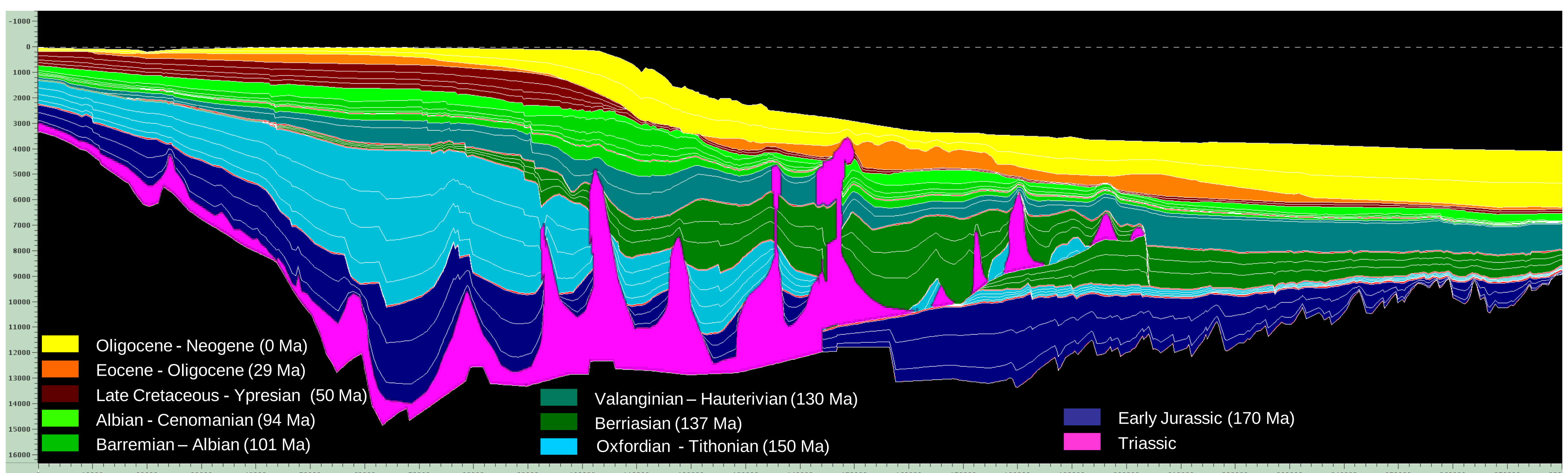
Modeling of Processes of Sedimentation and Erosion in 3D through time

The history of sedimentation within the basin is modeled with Dionisos® Software, which simulates the sediments deposition on topography through a diffusion equation.
In this modeling the topography, the type of lithology, the water flow and environmental conditions are taken into account.
The limit conditions of the model are on one hand the sources of sediment entering in the study domain on its borders and on the other hand the production of sediments by biologic activity.

Outputs of the modeling are :
- PaleoEnvironment Maps
- Lithology Maps
- Facies Maps
- Erosions



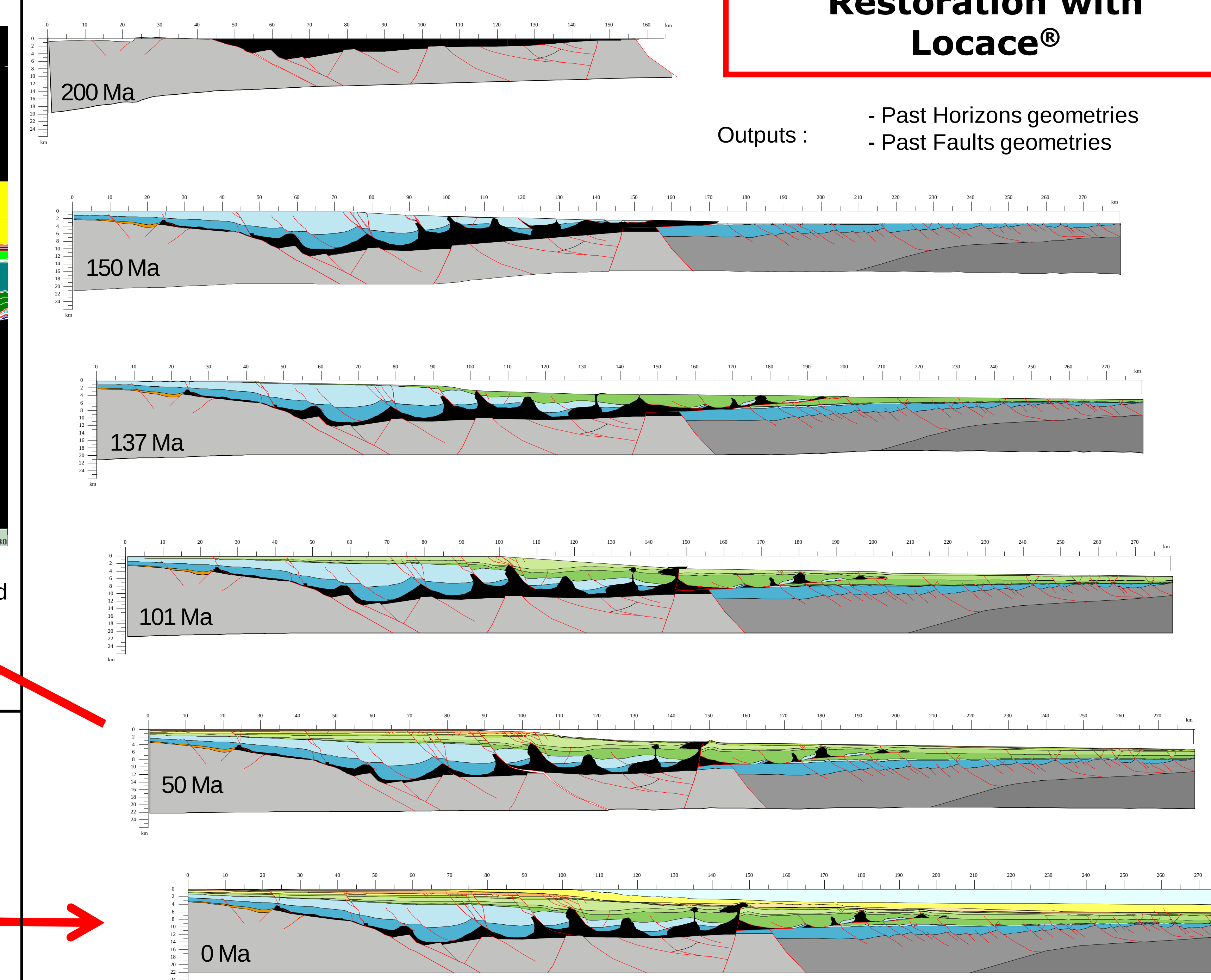
Temis2D® MODELING

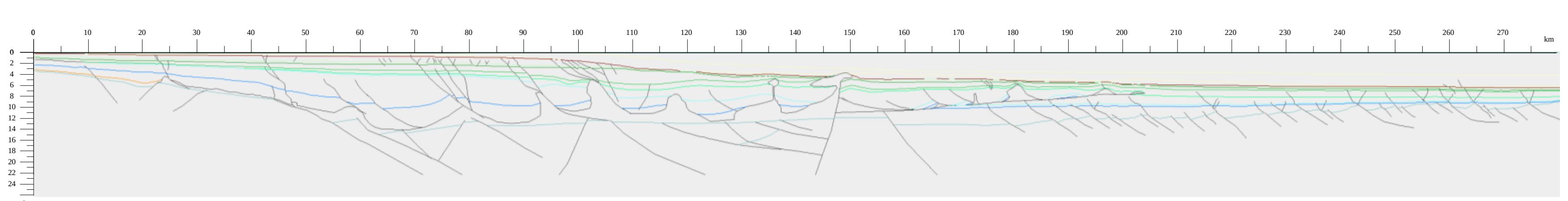


In Temis2D Modeling, present day geometry (horizons and faults) is defined from the Seismic interpretation, past geometries are obtained from the structural restoration, and the lithology distribution is derived from the Dionisos modeling.

Restoration with Locace®

Outputs :
- Past Horizons geometries
- Past Faults geometries





Seismic Interpretation

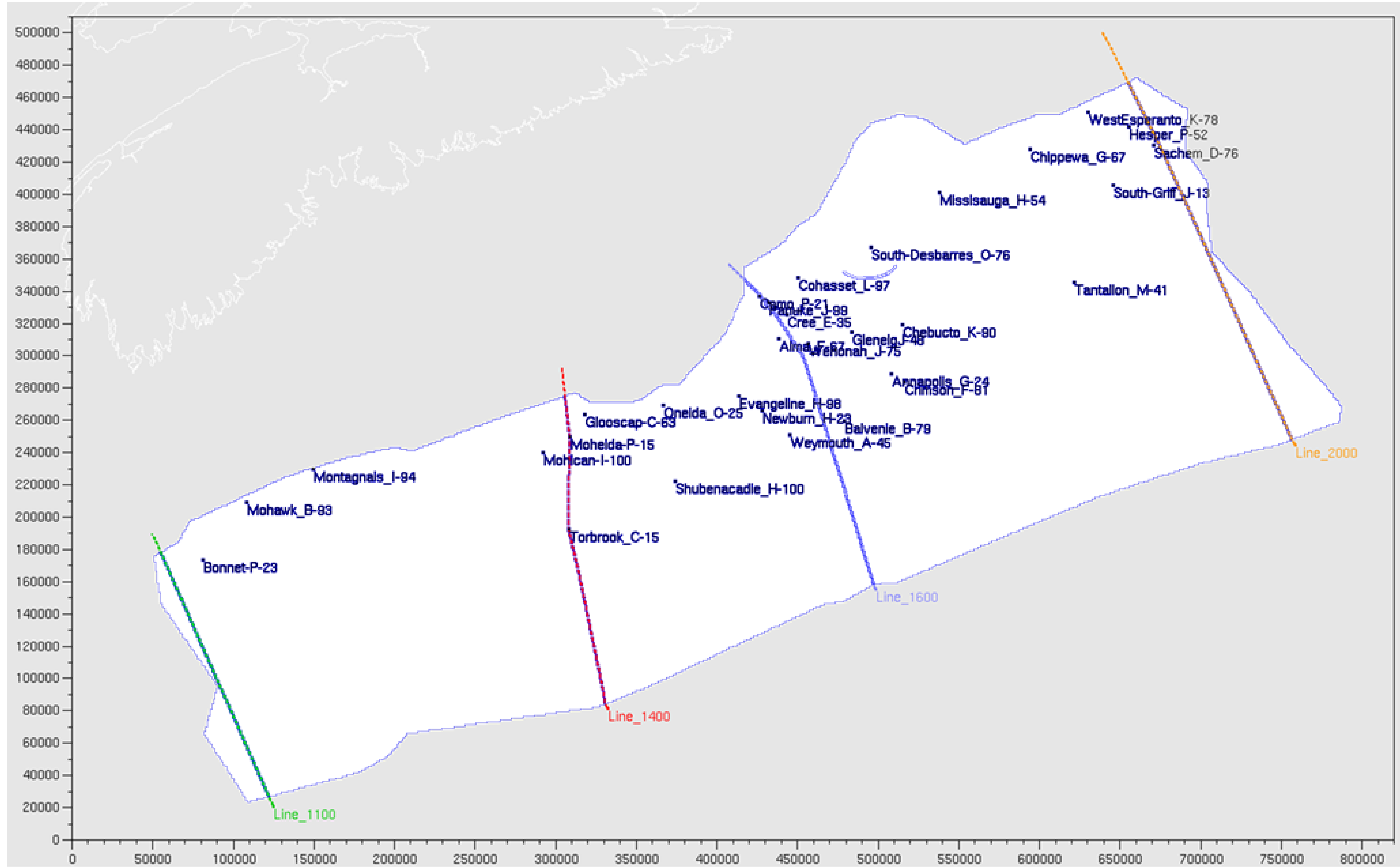
Outputs :
- Horizons geometries
- Faults geometries

Lithologies used in the Temis2D Models

Lithology Name	Shale (%)	Sand (%)	Carbonate Nearshore (%)	Carbonate Mudstone (%)
L01	100	0		
L02	80	20		
L03	60	40		
L04	40	60		
L05	20	80		
L06	0	100		
L07	70	0	30	
L08	50	20	30	
L09	30	40	30	
L10	10	60	30	
L11	40	0	60	
L12	20	20	60	
L13	0	40	60	
L14	0	0	100	
L15	80	0		20
L16	60	20		20
L17	40	40		20
L18	20	60		20
L19	50	0	30	20
L20	30	20	30	20
L21	10	40	30	20
L22	20	0	60	20
L23	0	20	60	20
L24	60	0		40
L25	40	20		40
L26	20	40		40
L27	30	0	30	40
L28	10	20	30	40
L29	0	0	60	40
L30	40	0		60
L31	20	20		60
L32	0	40		60
L33	10	0	30	60

Dionisos Modeling gives the lithology composition of each cell in the study domain in term of percentage of four pure poles that are Sand, Shale, Carbonate Near shore and Carbonate Mudstone.
33 different discrete lithologies have been defined (see table above). They have been designed to replace the continuous description of the lithologies in term of composition given by Dionisos modeling.

Location of the 4 sections modeled in Temis2D



Four Sections have been modeled with Temis2D, from west to east, NS1100, NS1400, NS1600 and NS2000.

Rifting events and basement thicknesses in oceanic domain

	Ages	Upper Crust (thickness)	Lower Crust (thickness)	Upper Mantle (thickness)	Bottom Limit condition
Before Rifting	**More than 225 Ma**	20 km Continental cust	12 km Continental crust	93 km	Isotherm 1300°C at Bottom
Beginning of Rifting	**225 Ma**	20 km Continental cust	12 km Continental crust	93 km	Rise of isotherm 1300°C
End of Rifting	**200 Ma**	4 km Oceanic crust	2.4 km Oceanic crust	93 km	Rise of isotherm 1300°C
After Rifting	**Less than 200 Ma**	4 km Oceanic crust	2.4 km Oceanic crust	93 km	Isotherm 1300°C at Bottom

Rifting was active between 225 and 200 Ma. The consequences on the temperature field are taken into account with the rise of the 1300°C isotherm and the thinning of the crust in the oceanic domain.

Common input Data of Temis2D studies

Name	Color	Compound Type	Mobility	Preferred HC Phase	Thermal Stability
C1-C5		Hydrocarbon	Mobile	Vapor	Stable
C6-C13		Hydrocarbon	Mobile	Liquid	Unstable
C14+		Hydrocarbon	Mobile	Liquid	Unstable
Non-HC		Non Hydrocarbon	Mobile	Vapor	Stable
NSO-Oil		Hydrocarbon	Mobile	Liquid	Unstable
NSO-SR		Hydrocarbon	Immobile	Liquid	Unstable
Precoke		Solid OM	Immobile		Unstable

Chemical Scheme
IFP 7 classes (+ coke)
5 mobile fractions (Behar et al. 2008)

Maturation of initial kerogens can generates 7 families of chemical components presented in the table above.
The "Non-HC" fraction mainly correspond to CO_2. "C" refers to the number of carbon in aliphatic chains.
"NSO" refers to Nitrogen/Sulfur/Oxygen rich molecules. This chemical fraction also contains heavy oils.
C1-C5 corresponds to the ***GAS*** and {C6-C13 ; C14+ ; NSO-Oil} correspond to the ***OIL***.
A "mobile" fraction can migrate in reservoir layers, while an "immobile" is solid or so viscous that it remains in the Source Rock.
An "unstable" fraction (such as C14+) can be altered by secondary cracking to generate lighter compounds (such as C6-C13) or C1-C5.

C1-C5	C6-C13	C14+	NSO-Heavy Oil
326 kg /m3	841 kg/m3	897 kg /m3	980 kg/m3

Average Densities at Surface Conditions (for the 4 mobile hydrocarbons classes)
Density are average values for each fraction.
These values are used for the calculation of volumes in surface conditions.

Source Rocks and Kerogen types

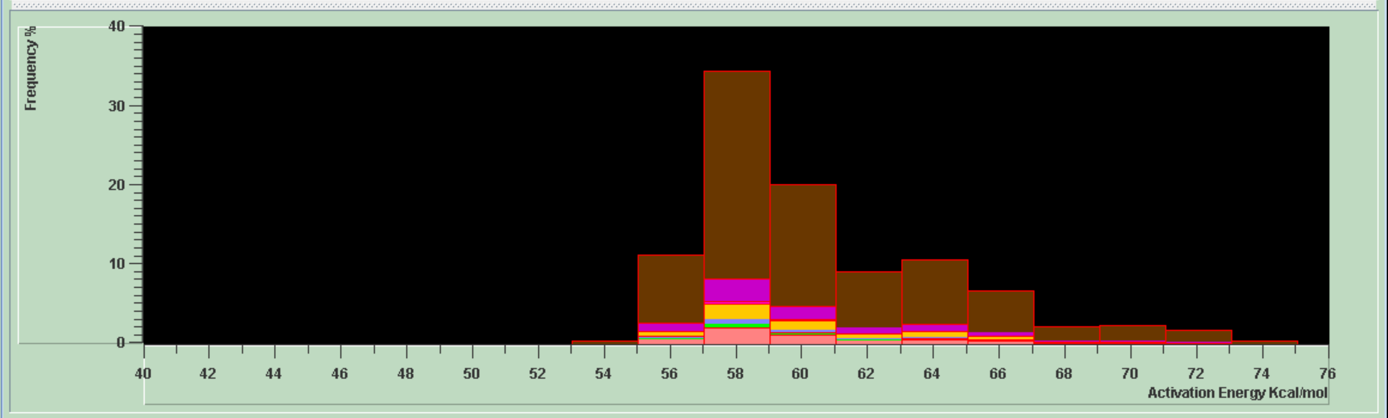
	Name	Kerogen type	Hydrogen Index (mg/gC)	S2 (mg/gC)	TOC (%)
1	Naskapi	Brent (type III)	235	2.35	1
2	Missisauga	Brent (type III)	235	2.35	1
3	Tithonian	Intermediate (type II – type III)	424	12.72	3
4	Misaine	Intermediate (type II – type III)	424	12.72	3
5	Pliensbachian	Menil (type II)	600	18	3

5 Source Rocks that correspond to 5 layers with a content of organic matter were defined for the Temis 2D models, whether 2D and 3D.
They are by chronologic order:

- Pliensbachian (196Ma)
- Misaine (or Callovian 160Ma)
- Tithonian (148 Ma)
- Missisauga (or Valanginian 136 Ma)
- Naskapi (or Aptian 122 Ma)

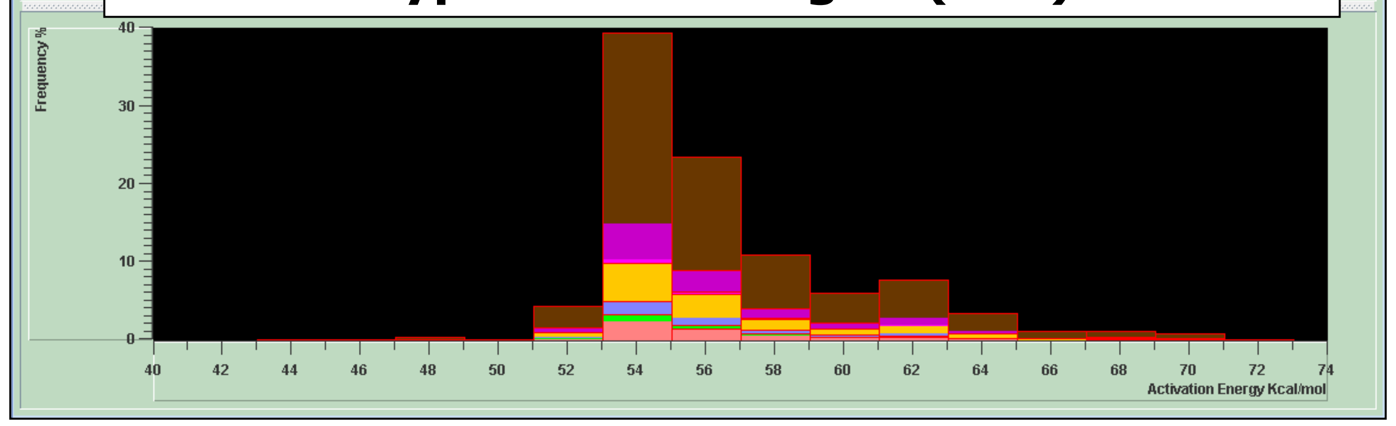
	Activation Energy Kcal/mol	Arrhenius Coefficient 1/s	Frequency %	Sums of Fractions %	C1-C5 %	C6-C13 %	C14+ %	Non-HC %	NSO-Oil %	NSO-SR %	Precoke %	Coke %
1	54.0	3.1E15	0.51	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
2	56.0	3.1E15	11.32	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
3	58.0	3.1E15	34.51	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
4	60.0	3.1E15	20.17	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
5	62.0	3.1E15	9.15	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
6	64.0	3.1E15	10.72	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
7	66.0	3.1E15	6.77	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
8	68.0	3.1E15	2.3	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
9	70.0	3.1E15	2.38	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
10	72.0	3.1E15	1.74	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
11	74.0	3.1E15	0.43	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0

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



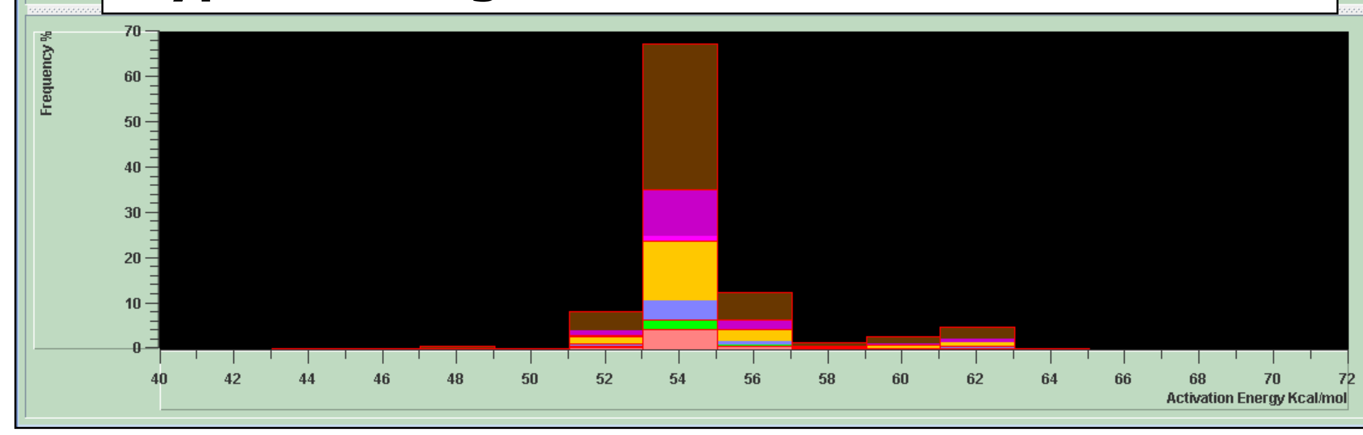
	Activation Energy Kcal/mol	Arrhenius Coefficient 1/s	Frequency %	Sums of Fractions %	C1-C5 %	C6-C13 %	C14+ %	Non-HC %	NSO-Oil %	NSO-SR %	Precoke %	Coke %
1	44.0	1.64E14	0.09	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
2	46.0	1.64E14	0.11	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
3	48.0	1.64E14	0.44	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
4	50.0	1.64E14	0.16	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
5	52.0	1.64E14	4.49	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
6	54.0	1.64E14	39.35	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
7	56.0	1.64E14	23.55	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
8	58.0	1.64E14	10.92	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
9	60.0	1.64E14	6.04	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
10	62.0	1.64E14	7.82	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
11	64.0	1.64E14	3.53	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
12	66.0	1.64E14	1.17	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
13	68.0	1.64E14	1.22	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
14	70.0	1.64E14	0.89	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
15	72.0	1.64E14	0.22	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0

Type II-III kerogen (mix)



	Activation Energy Kcal/mol	Arrhenius Coefficient 1/s	Frequency %	Sums of Fractions %	C1-C5 %	C6-C13 %	C14+ %	Non-HC %	NSO-Oil %	NSO-SR %	Precoke %	Coke %
1	44.0	1.64E14	0.17	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
2	46.0	1.64E14	0.22	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
3	48.0	1.64E14	0.88	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
4	50.0	1.64E14	0.32	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
5	52.0	1.64E14	8.47	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
6	54.0	1.64E14	67.38	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
7	56.0	1.64E14	12.58	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
8	58.0	1.64E14	1.67	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
9	60.0	1.64E14	2.93	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
10	62.0	1.64E14	4.92	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
11	64.0	1.64E14	0.28	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
12	66.0	1.64E14	0.03	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
13	68.0	1.64E14	0.05	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
14	70.0	1.64E14	0.1	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0

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



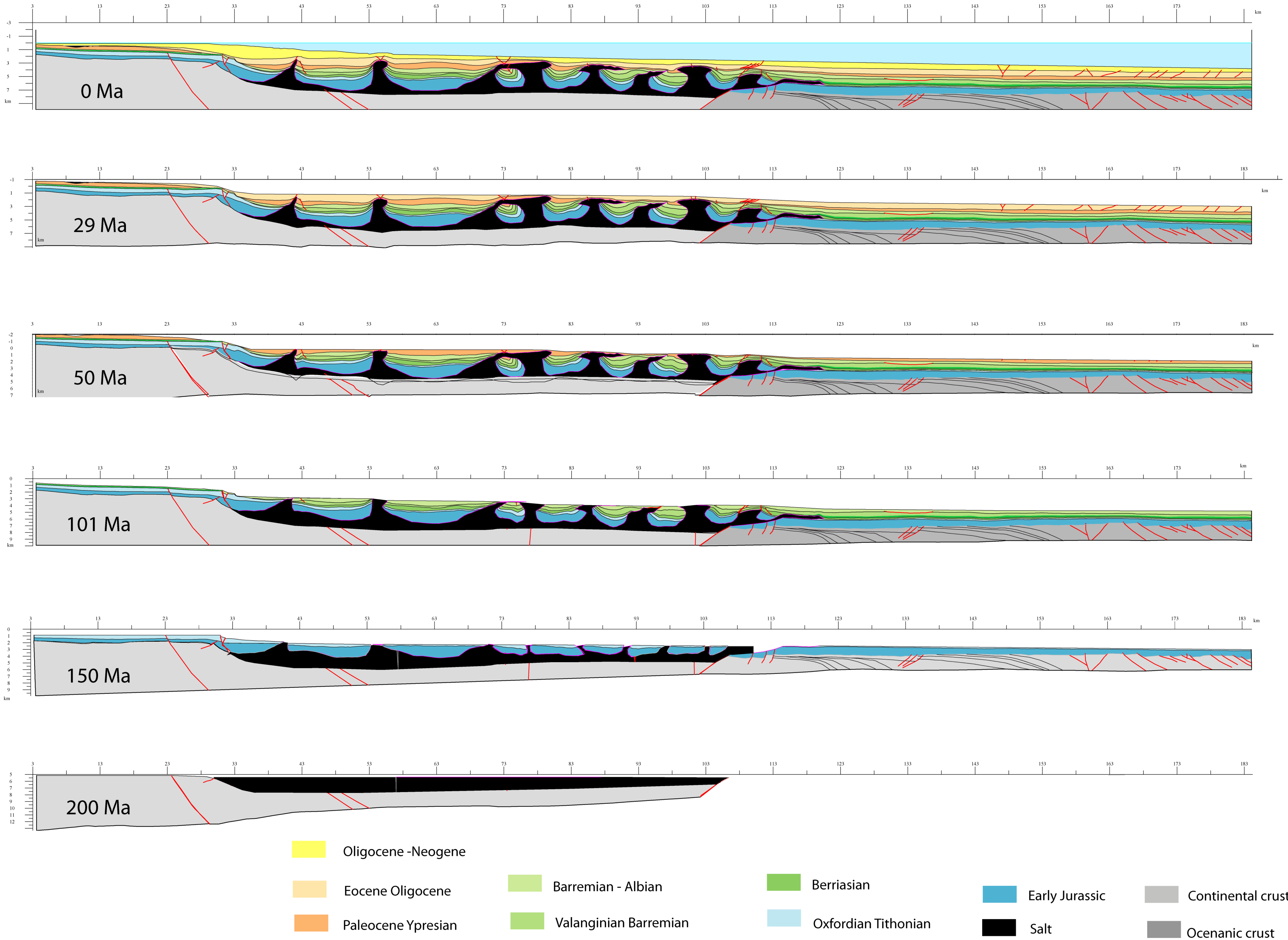
Kinetic Scheme
Kerogen maturation follows "kinetic schemes" specific to each kerogen type. The maturation process is divided in "n" parallel chemical reactions (11 to 15 in that case) which have their own reaction speeds. Reaction speed is calculated with the Arrhenius Law and depends on: the Activation Energy, the Arrhenius Coefficient (specific to each chemical reaction), and the temperature. Each reaction generates chemical fractions defined by the chemical scheme.
Tables and graphs detail the 3 kinetic schemes used in this study (Type III, Type II-III, Type II). These schemes come from the Temis Default Library (specific data not available for Nova Scotia).
Secondary cracking reactions also follow kinetics laws.

CHAPTER 7-2

BASIN MODELING – TEMIS 2D

7-2-2

Section NS 1100 Modeling


0 Ma
29 Ma
50 Ma
101 Ma
150 Ma
200 Ma
Oligocene -Neogene
Eocene Oligocene
Paleocene Ypresian
Barremian - Albian
Valanginian Barremian
Berriasian
Oxfordian Tithonian
Early Jurassic
Salt
Continental crust
Ocenanic crust

BASIN MODELING – TEMIS 2D

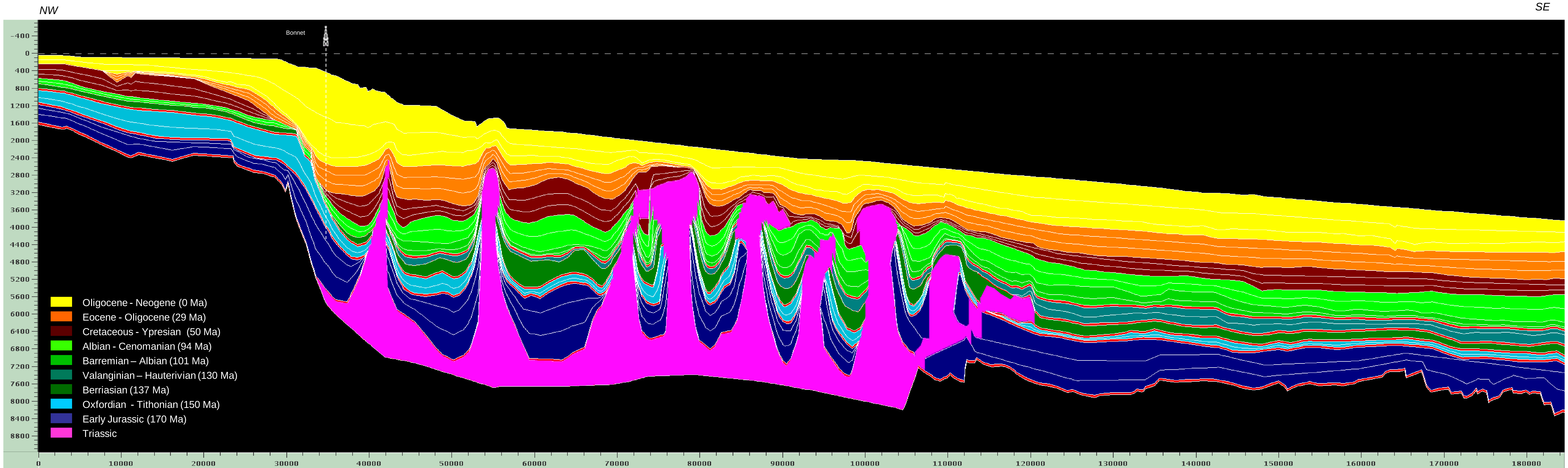


Figure 1: Stratigraphy of the Section NS1100 at Present day

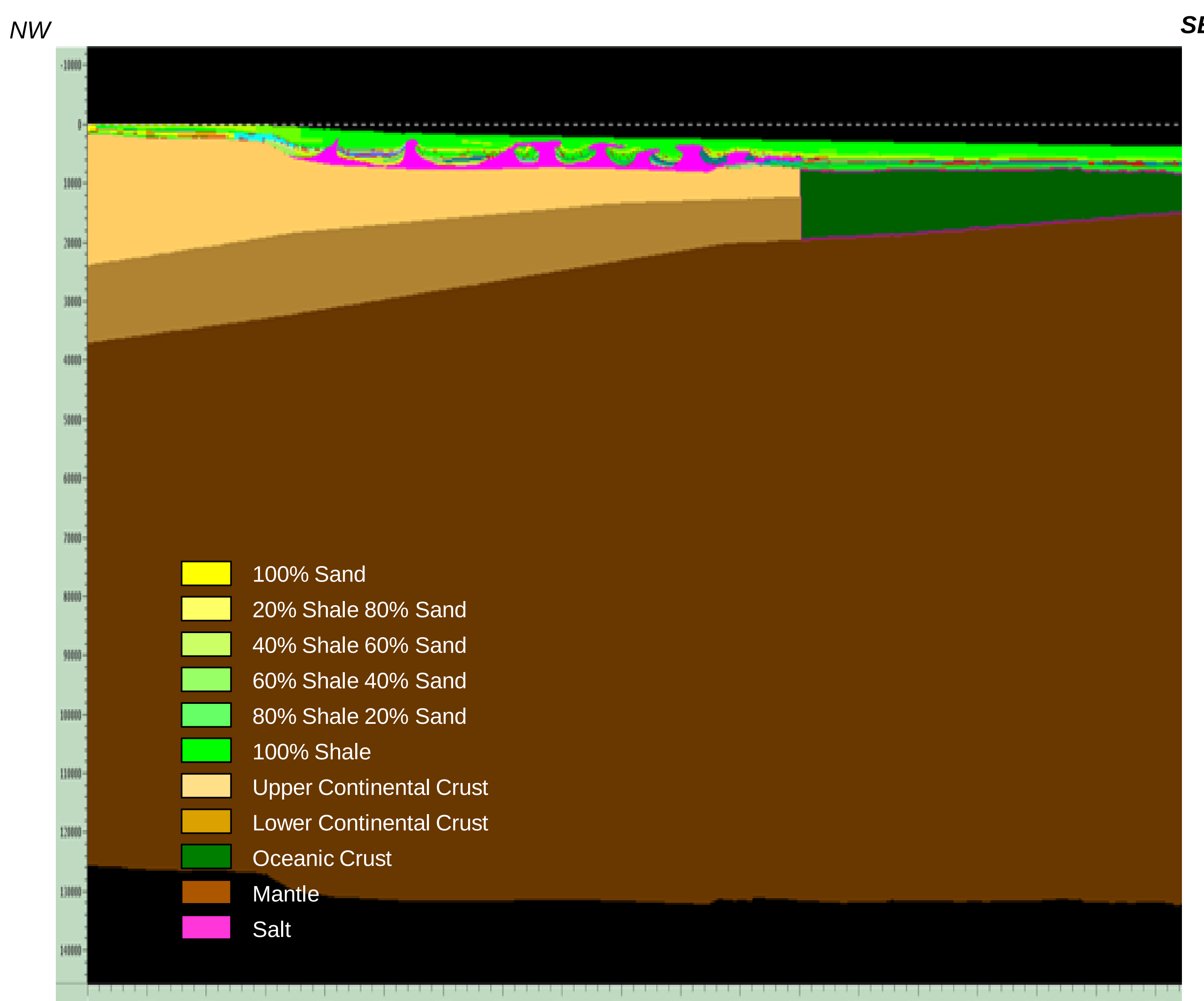


Figure 2: Lithosphere geometry of Section NS1100 at Present day

The limit between continental and oceanic crust domains is at kilometer 120 in the model. The crust maximum thickness is at the north of the section where the value is close to 40 km. On the contrary the crust thickness is minimum at the south of the section where it is close to 8 km.

The Section NS1100 is 185 kilometers in length and is located at the west limit of the study domain.
The northern part of the section lies on the continental platform and the southern part lies on the oceanic domain.

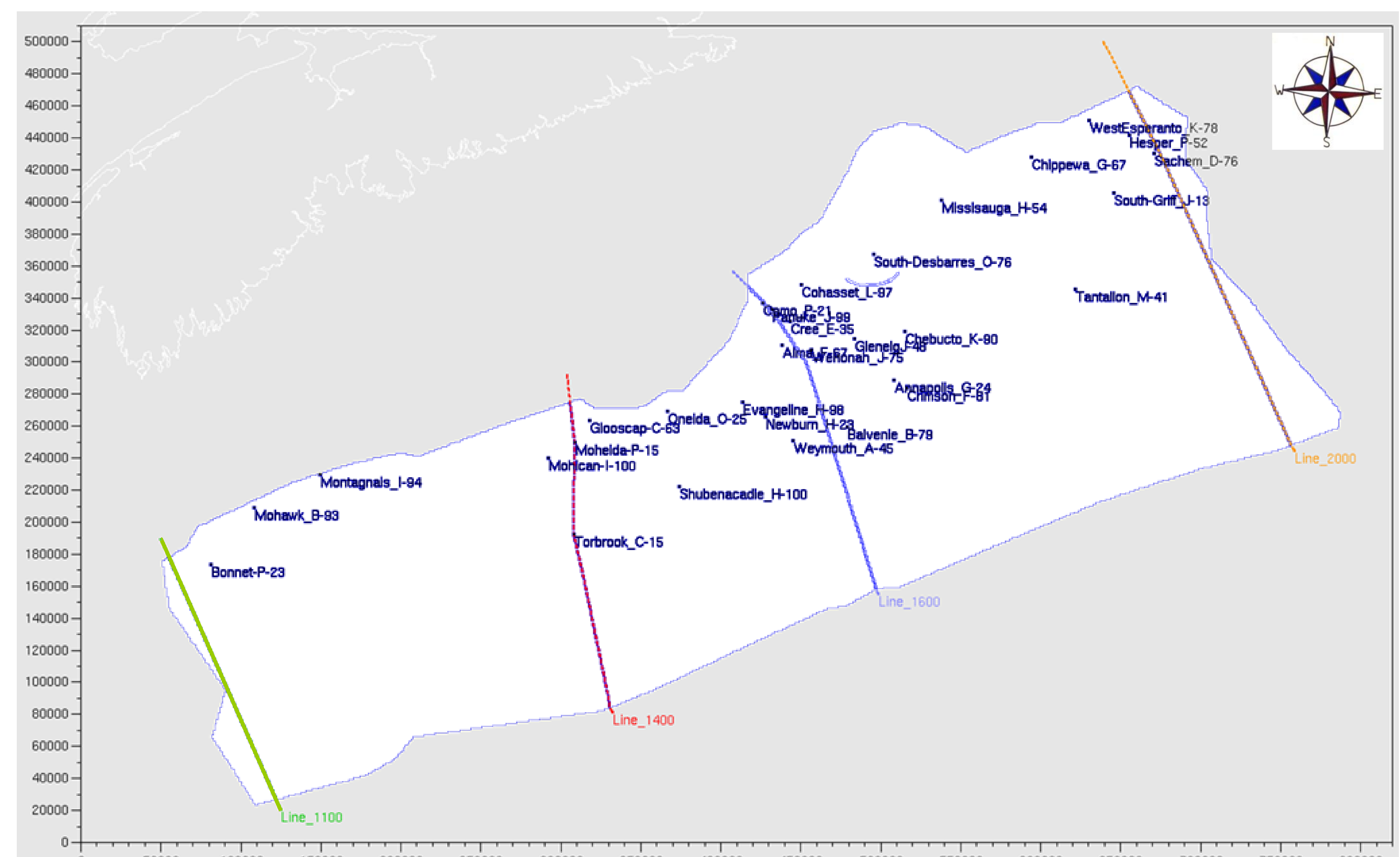


Figure 3: Location of Section NS1100 on Map

PL. 7-2-2-2a **Stratigraphy, Basement geometry and Location Map of Section NS1100**

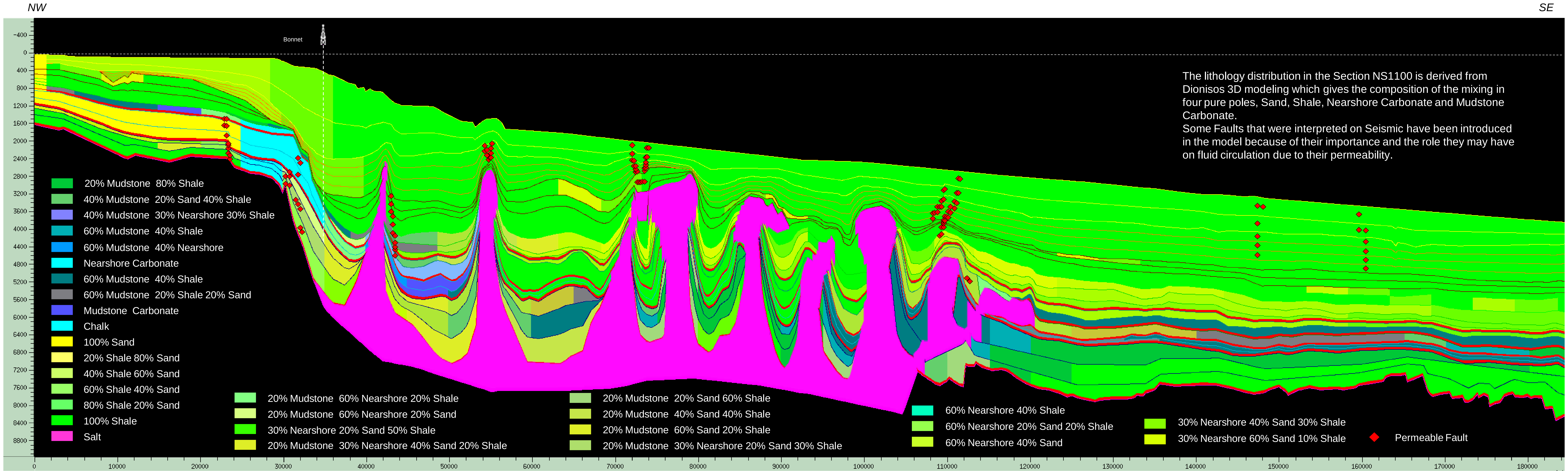


Figure 1: Lithology and Fault zones of Section NS1100 at Present day

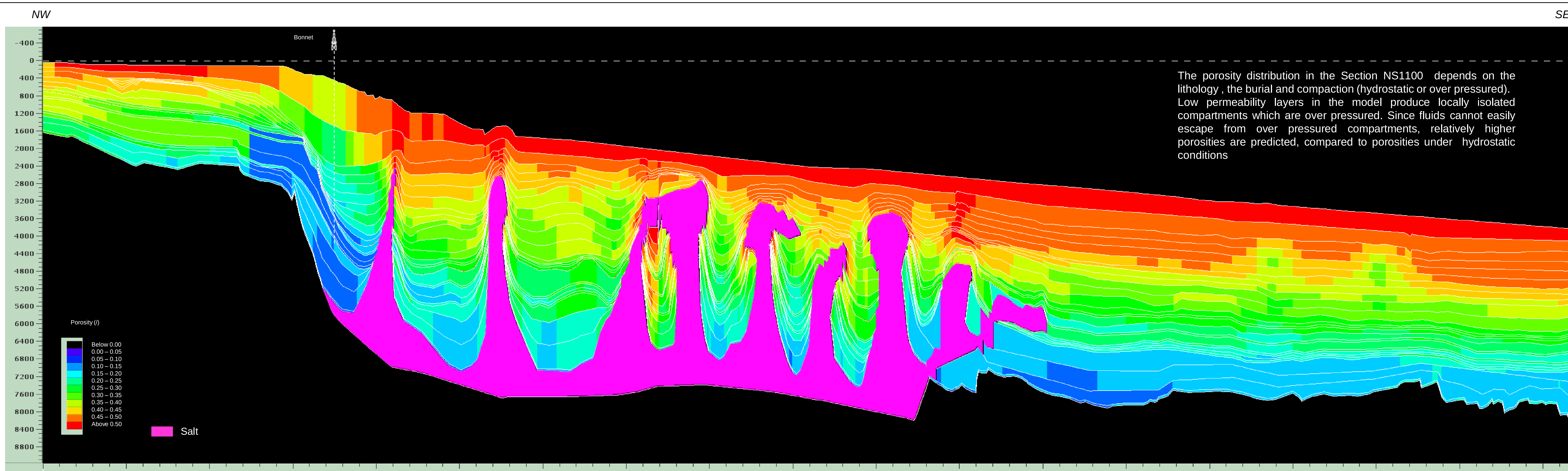


Figure 2: Porosity of Section NS1100 at Present day

BASIN MODELING – TEMIS 2D

PLAY FAIRWAY ANALYSIS - OFFSHORE NOVA SCOTIA - CANADA – June 2011

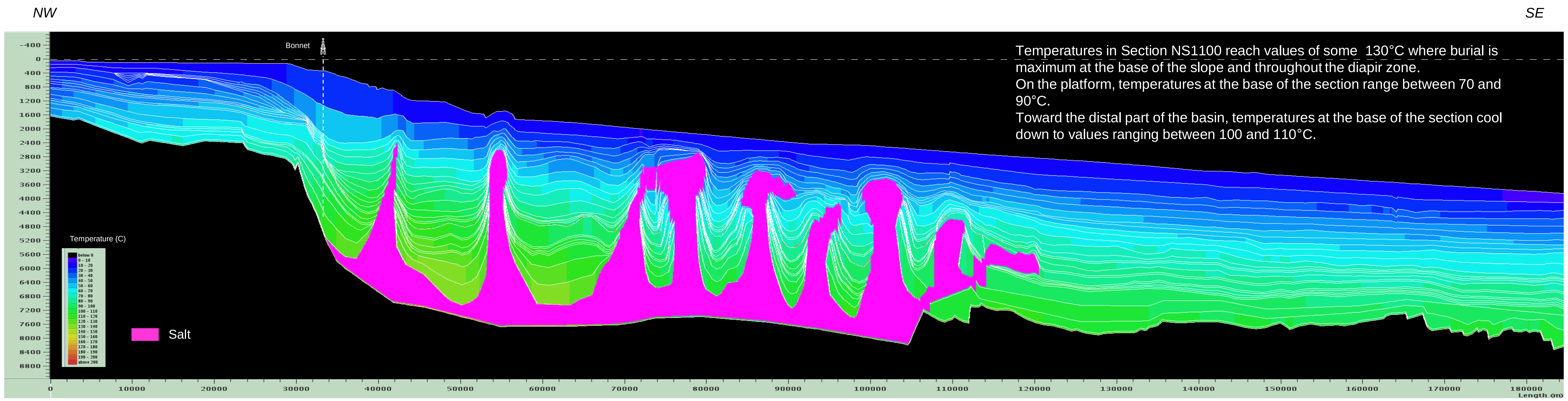
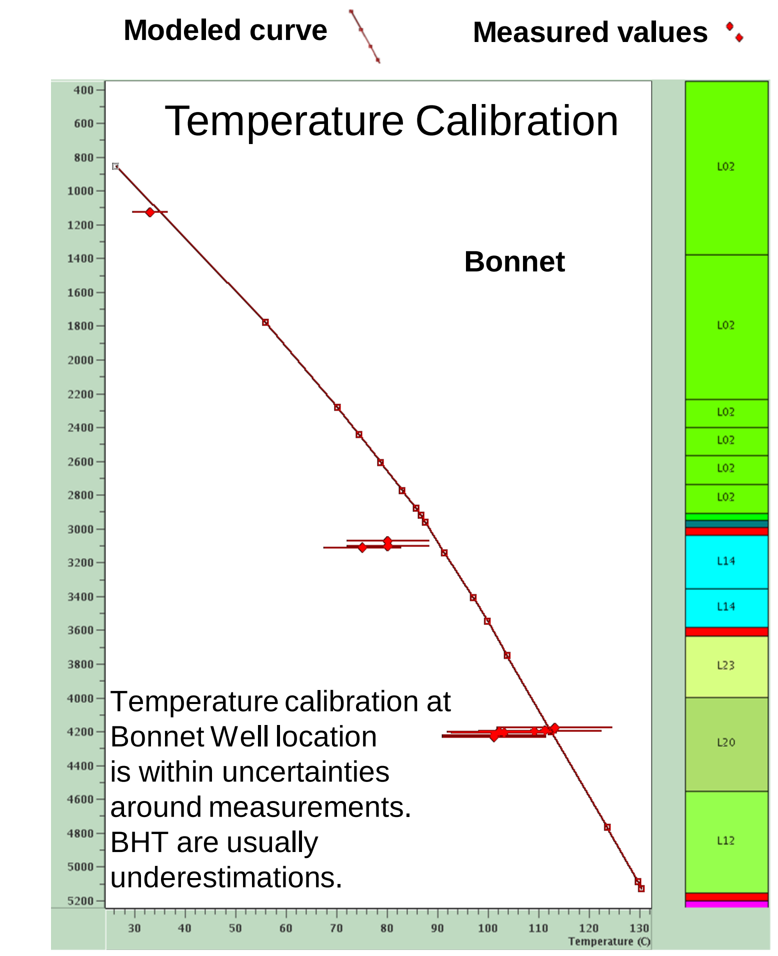


Figure 1: Temperature Field



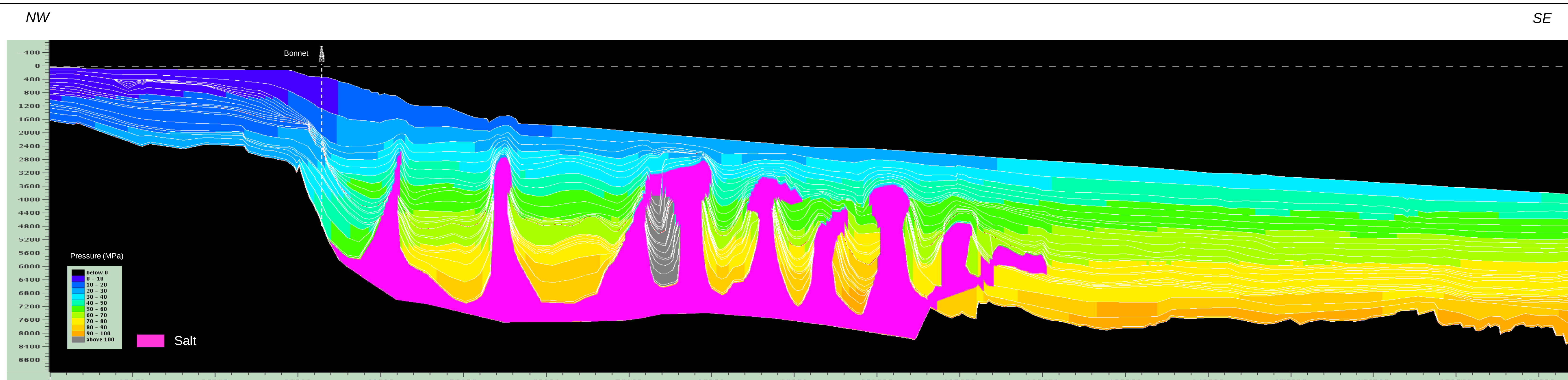
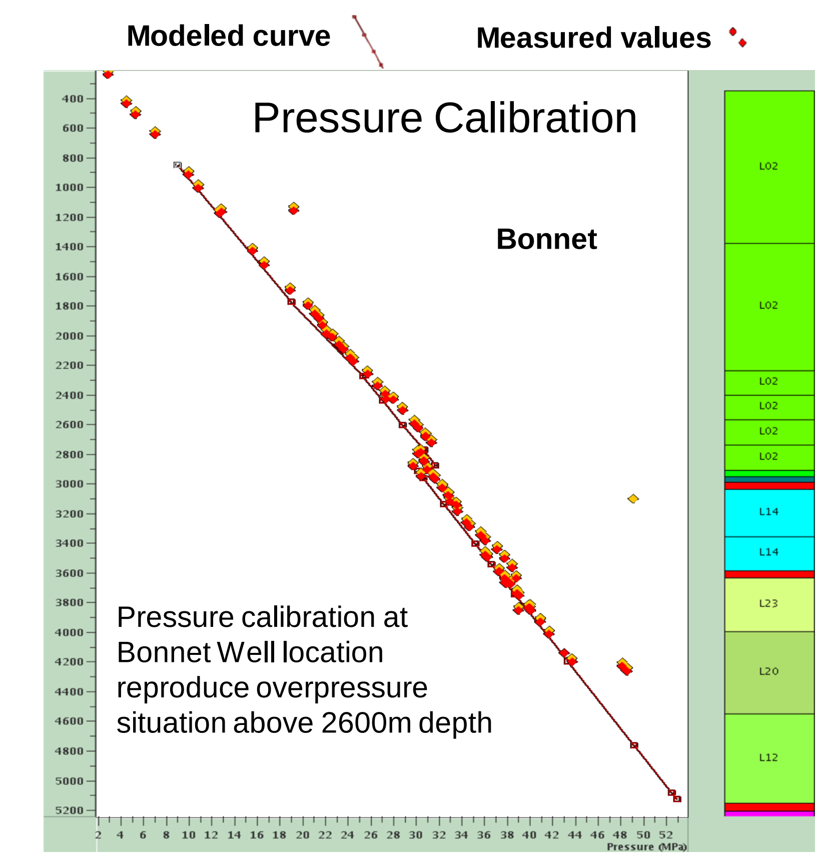


Figure 2: Pressure Field



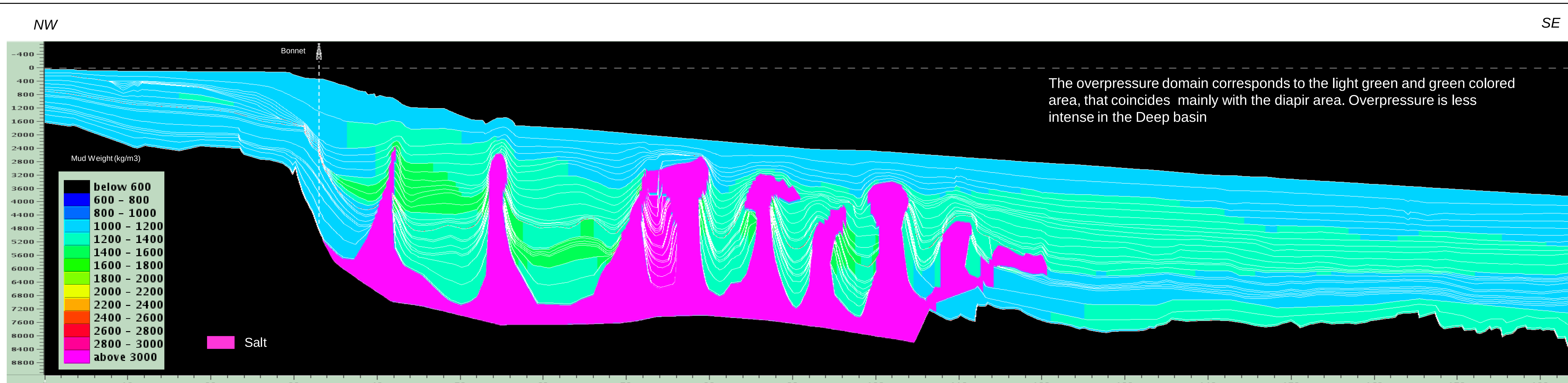
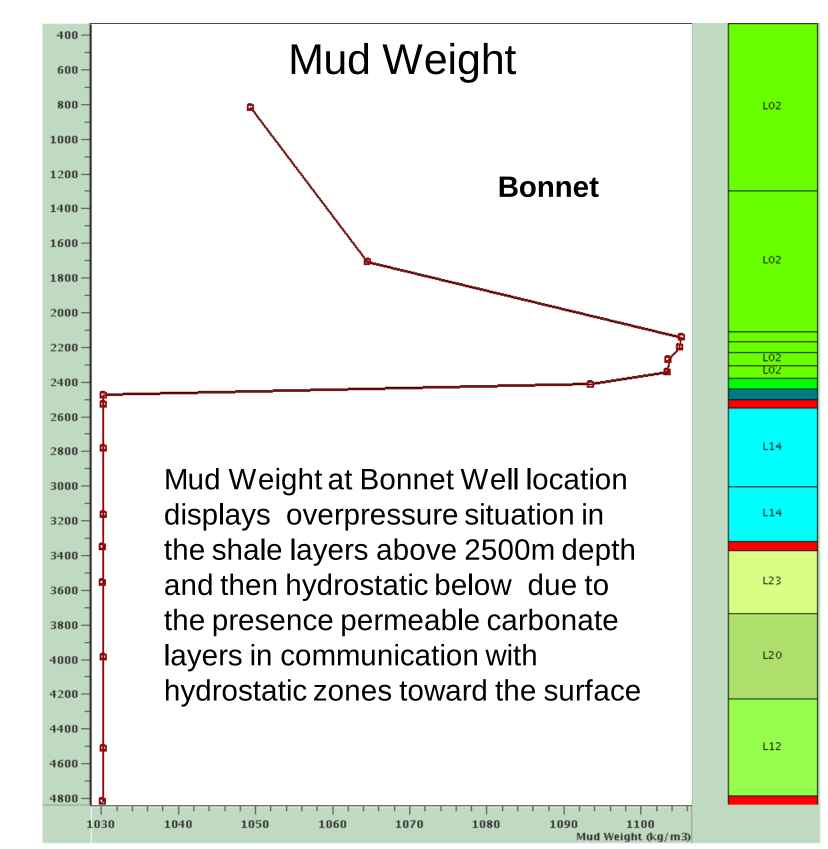
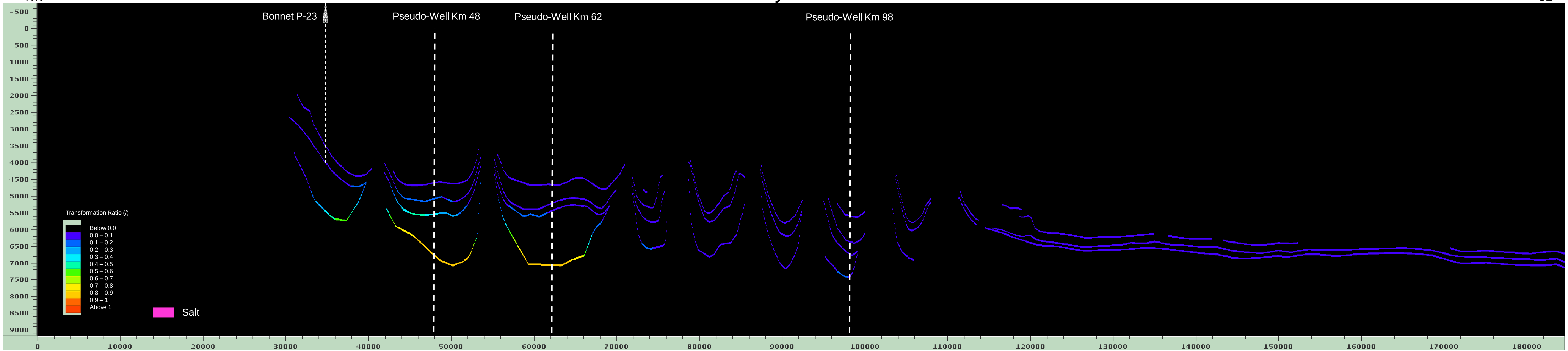


Figure 3: Overpressure (Mud Weight) Field

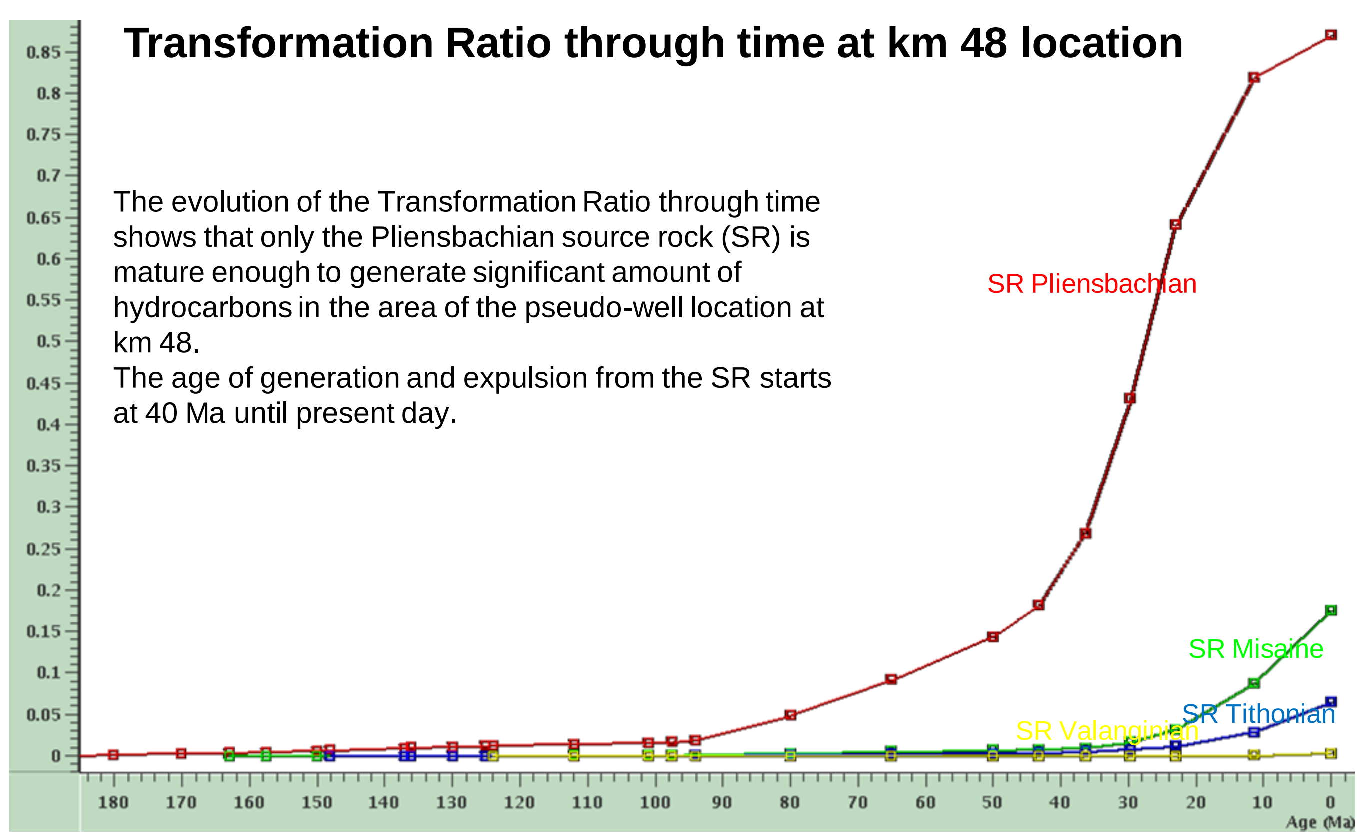


PL. 7-2-2-3a **Temperature and Pressure Calibration of Section NS1100**

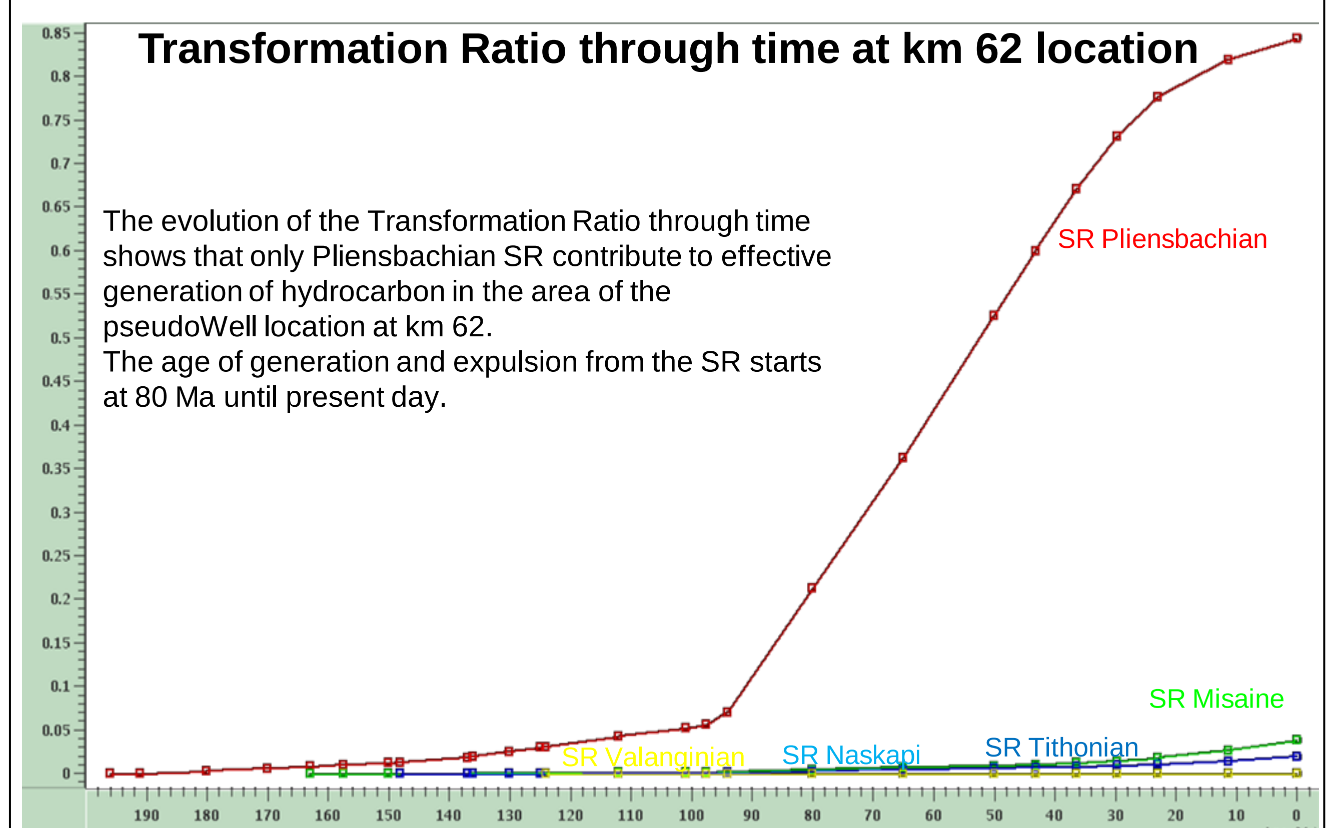
Transformation Ratio at Present Day for the Source Rocks of Section NS1100



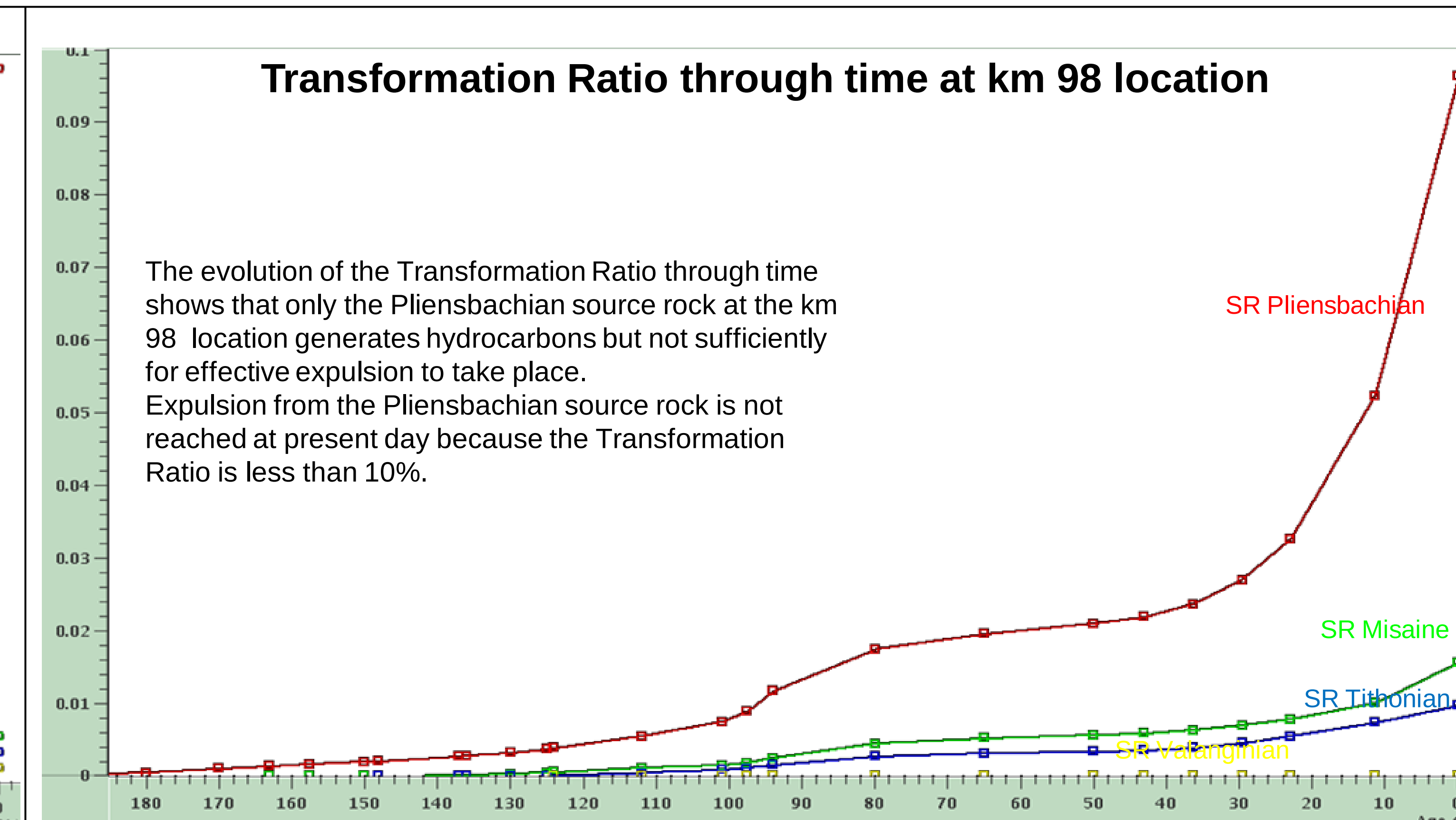
Transformation Ratio through time at km 48 location



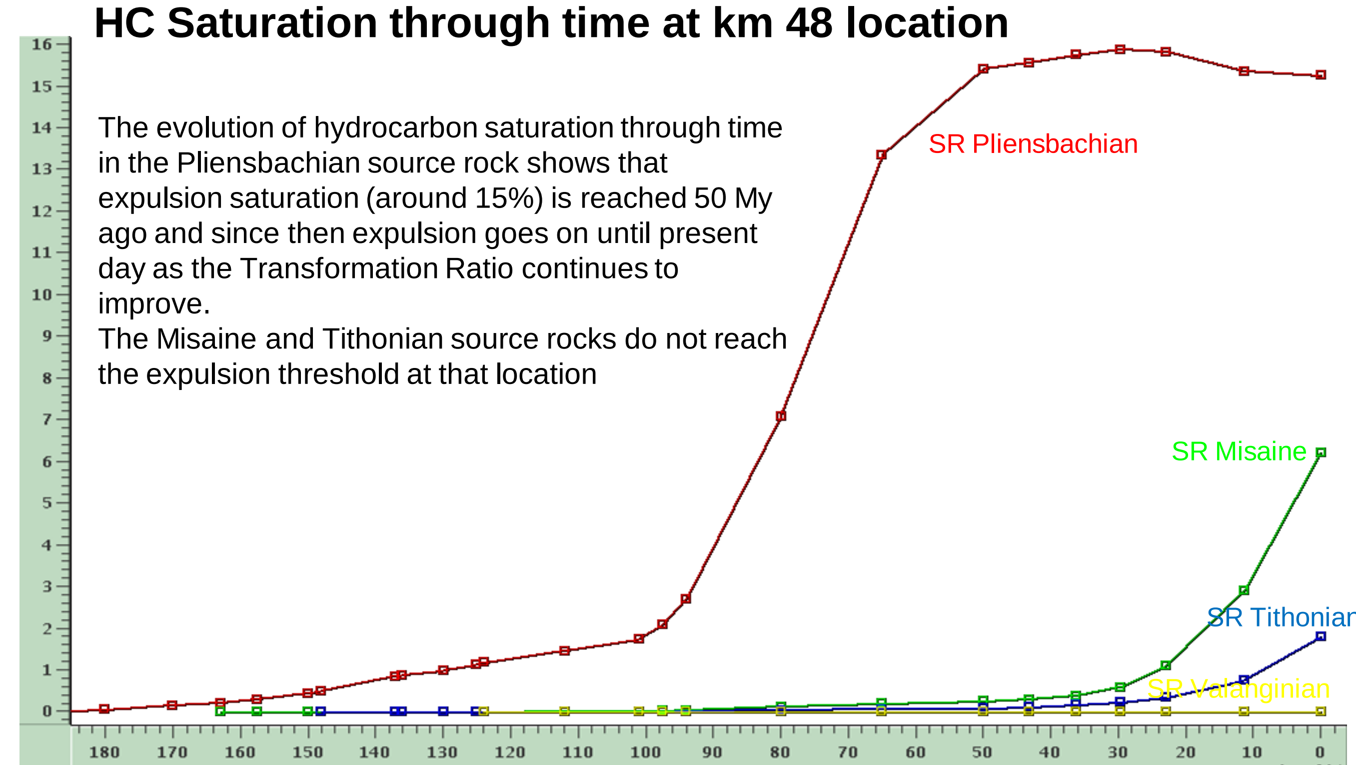
Transformation Ratio through time at km 62 location



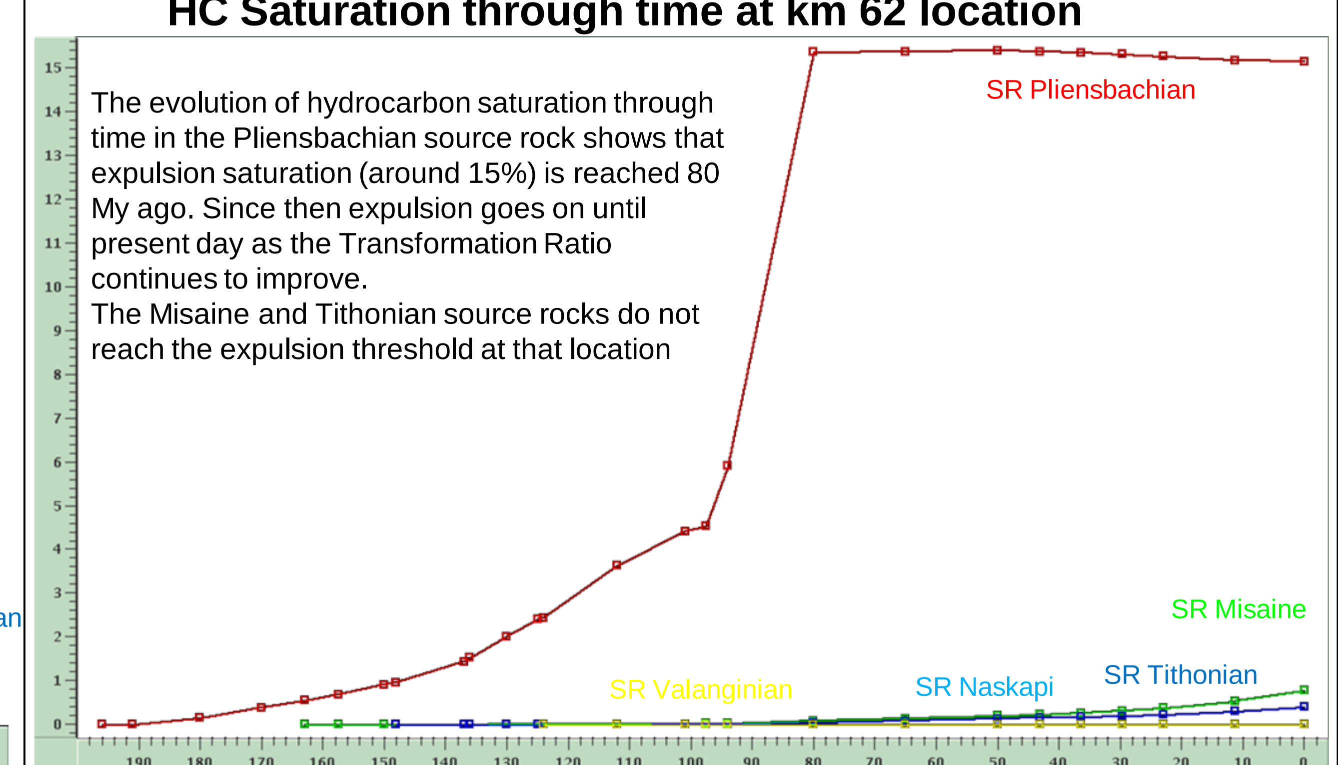
Transformation Ratio through time at km 98 location



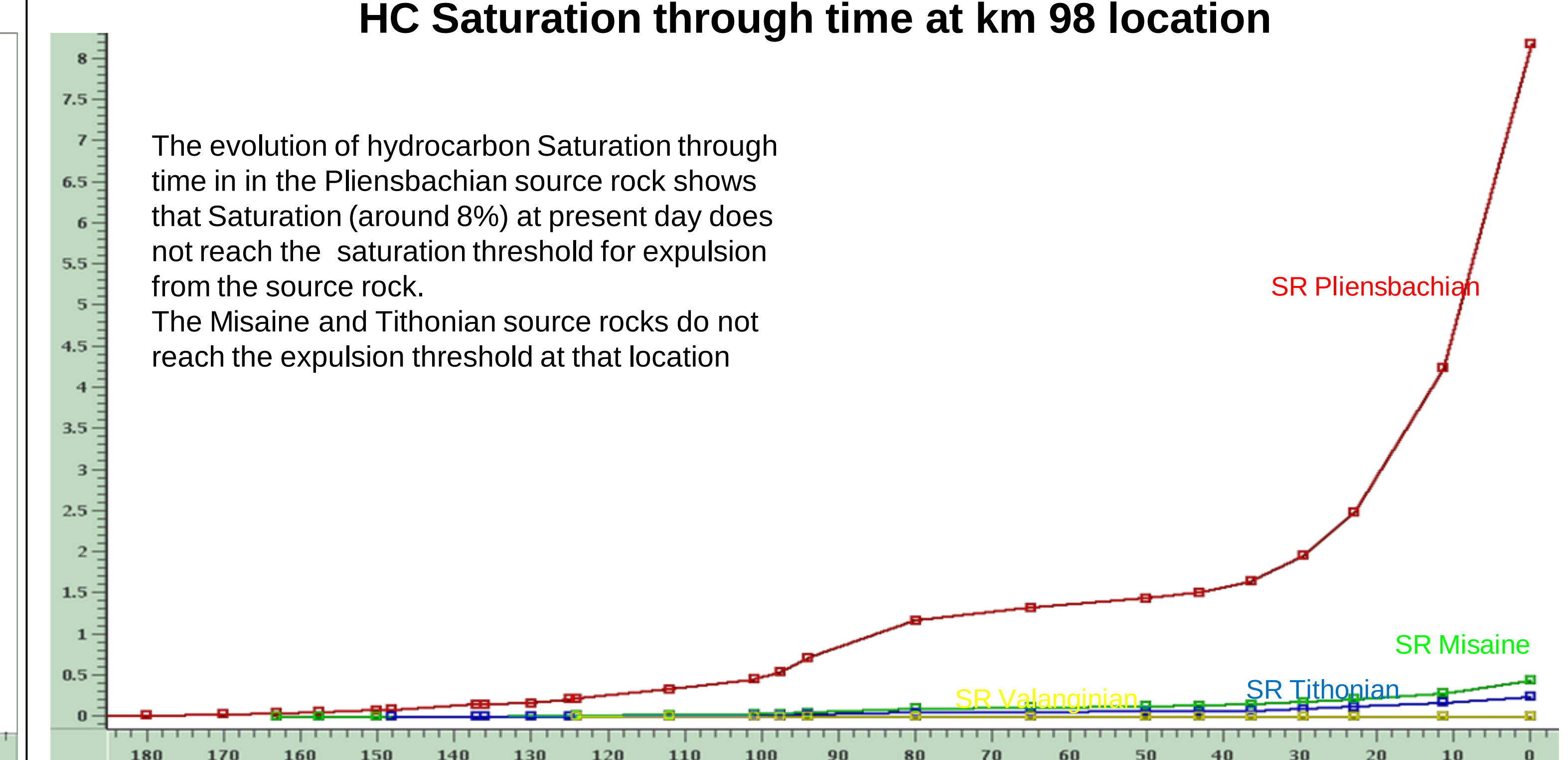
HC Saturation through time at km 48 location



HC Saturation through time at km 62 location



HC Saturation through time at km 98 location



Section NS1100 - Transformation Ratio and Hydrocarbon Saturation Through Time

PL. 7-2-2-3b

BASIN MODELING – TEMIS 2D

Figure 1: Ypresian - 50 Ma

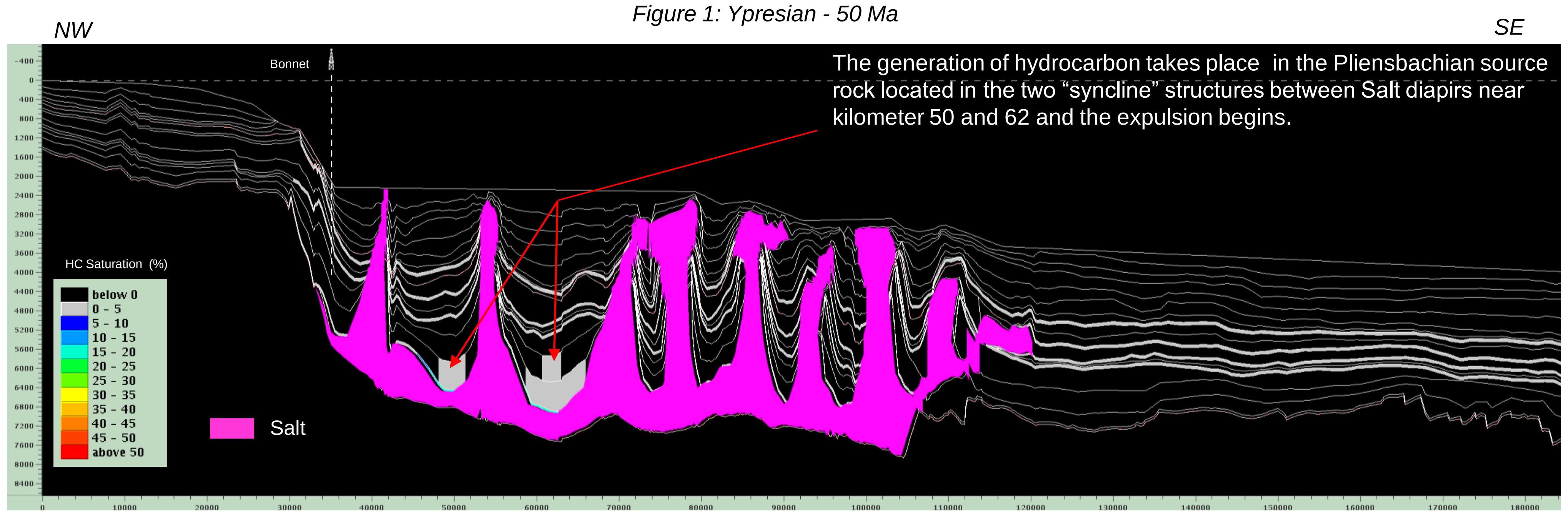


Figure 2: Priabonian – 36.4 Ma

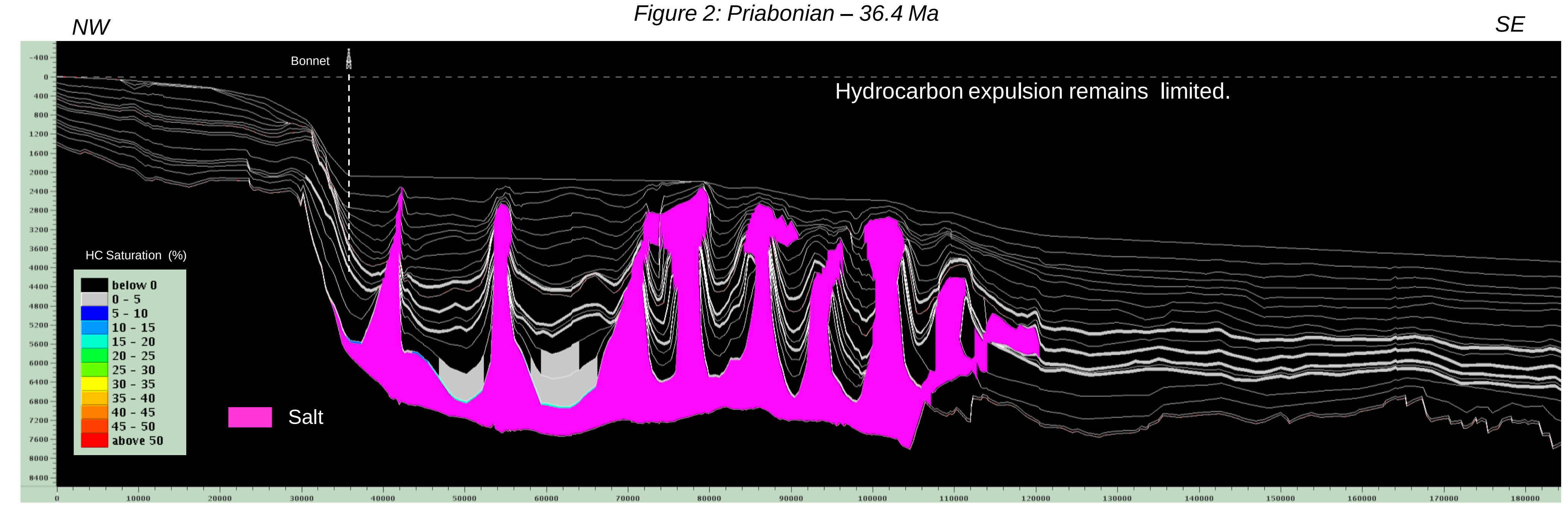


Figure 3: Chattian - 23 Ma

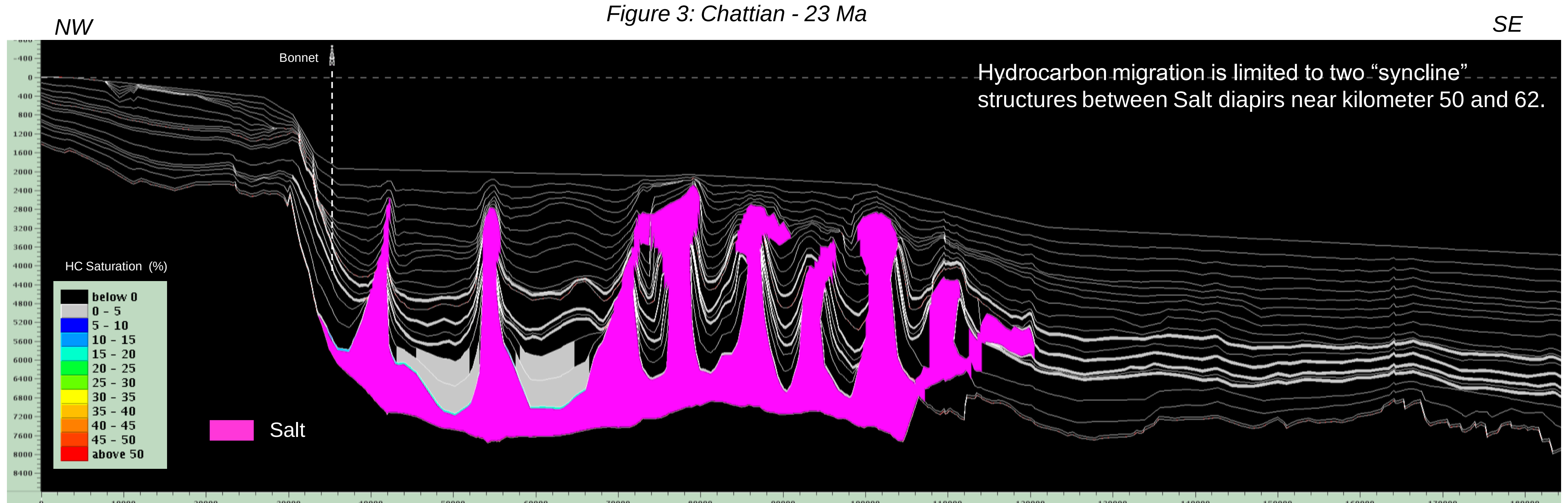


Figure 4: Serravallian – 11.4 Ma

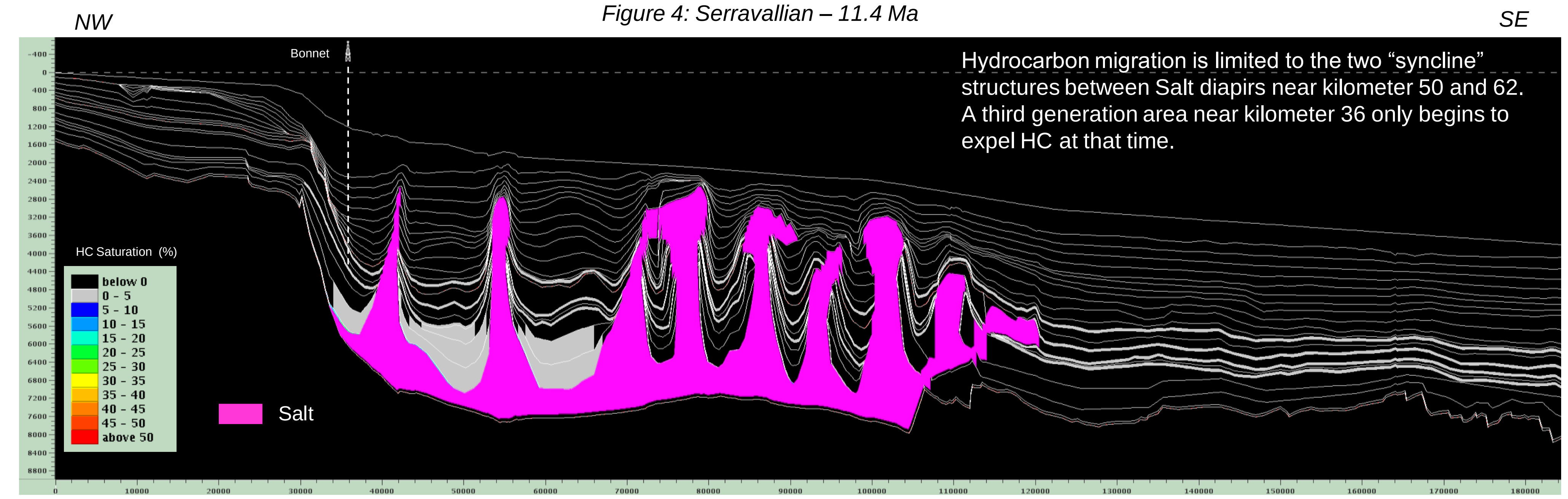
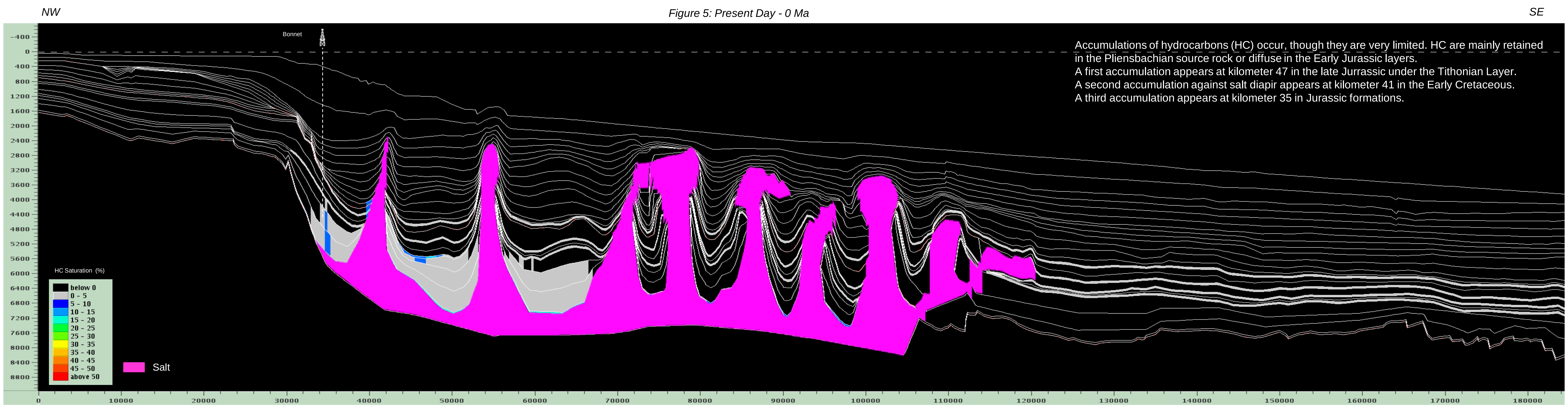


Figure 5: Present Day - 0 Ma



PL. 7-2-2-4a **HC Saturation through time of Section NS 1100**

Figure 1: R0 Maturity

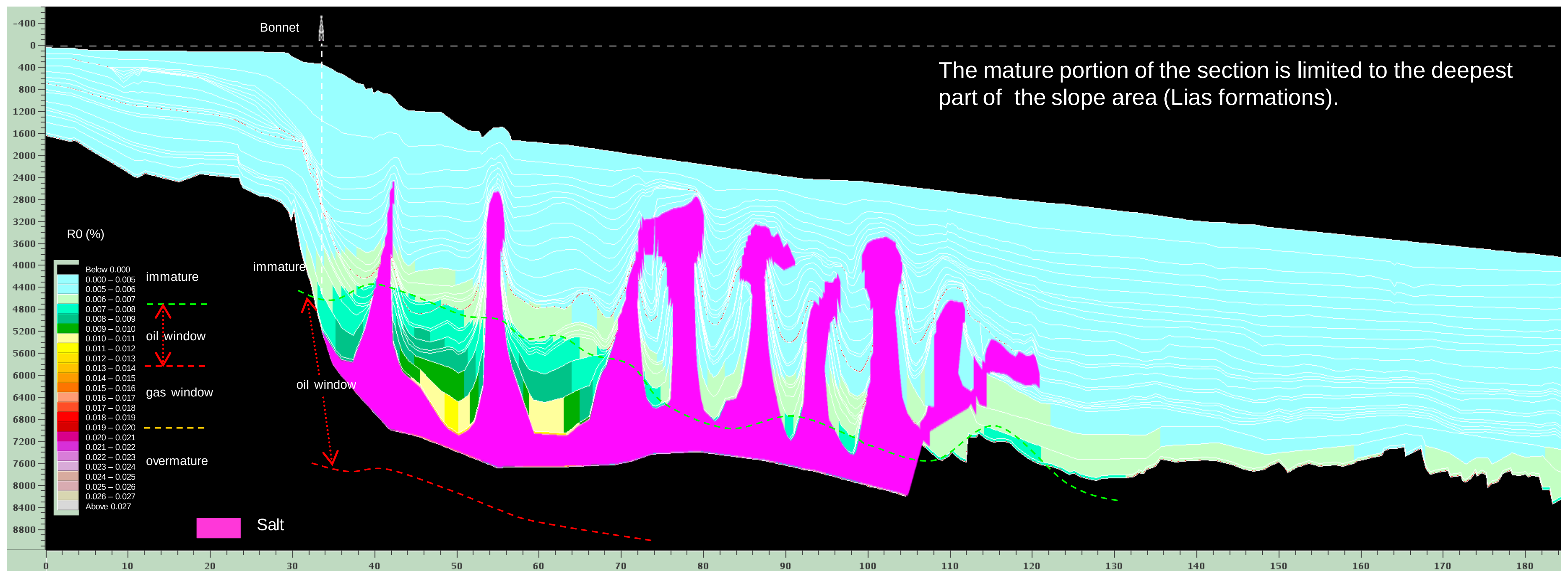


Figure 2: Total HC Mass

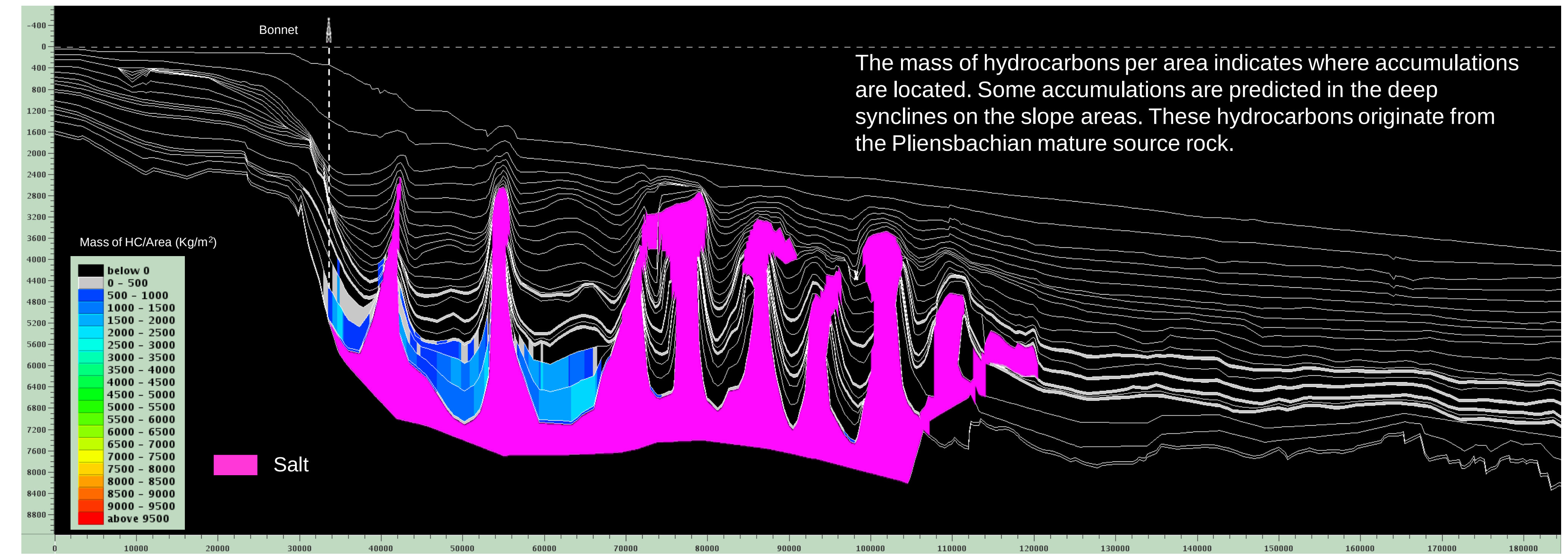


Figure 3: Fraction C1-C5

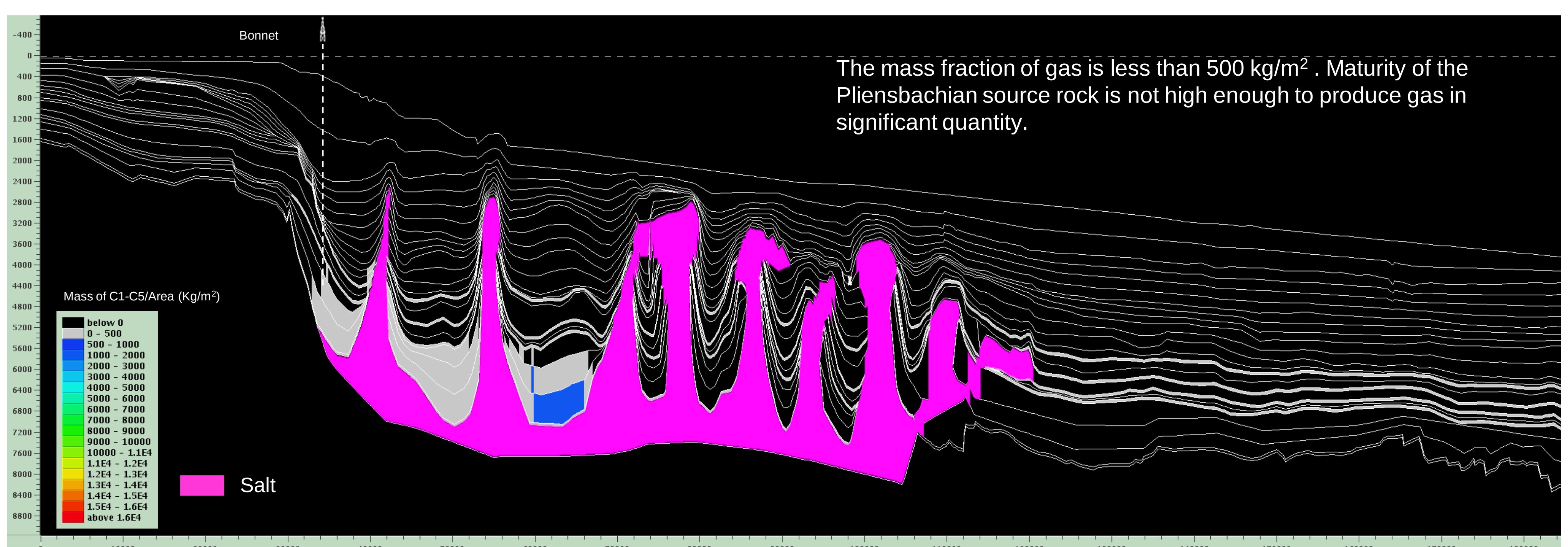


Figure 4: Fraction C6-C13

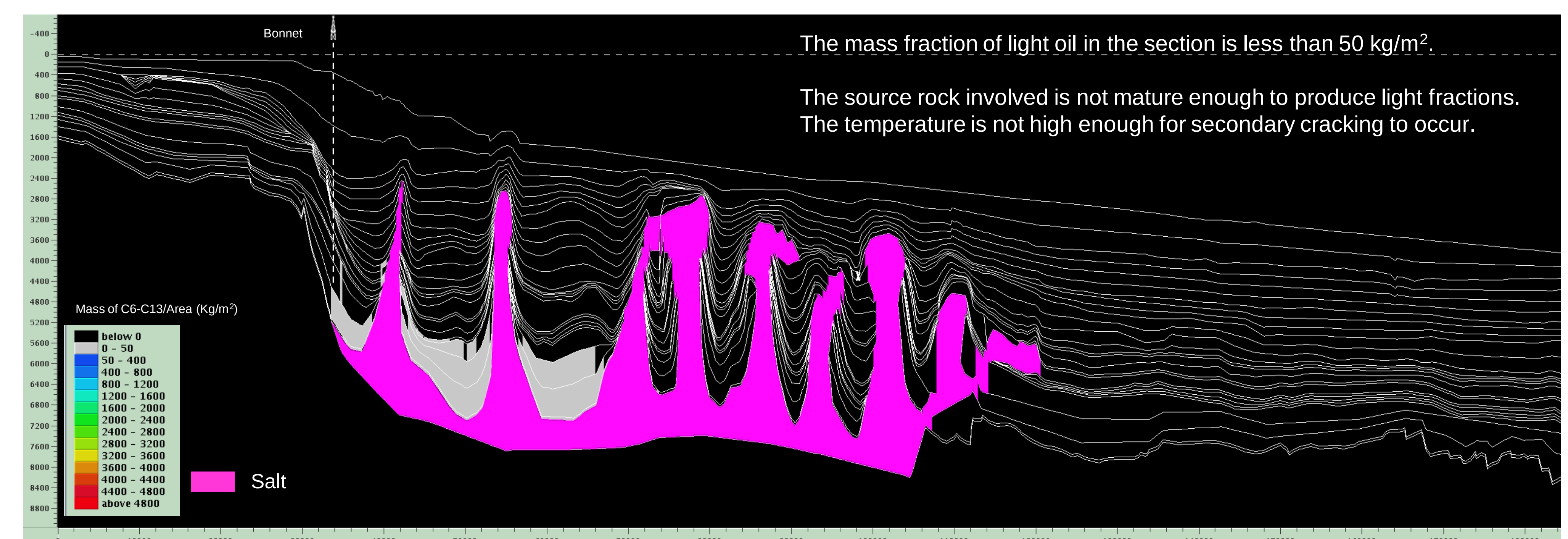


Figure 5: Fraction Nitrogen / Sulfur / Oxygen OIL

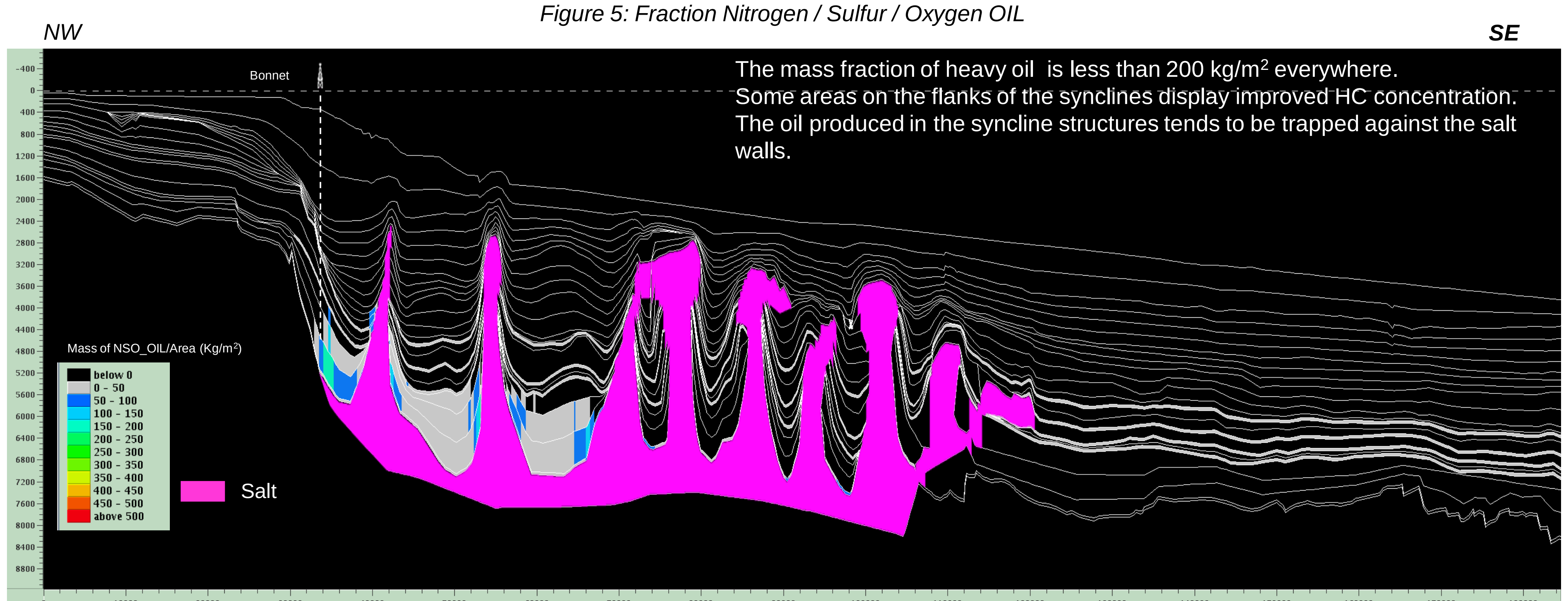
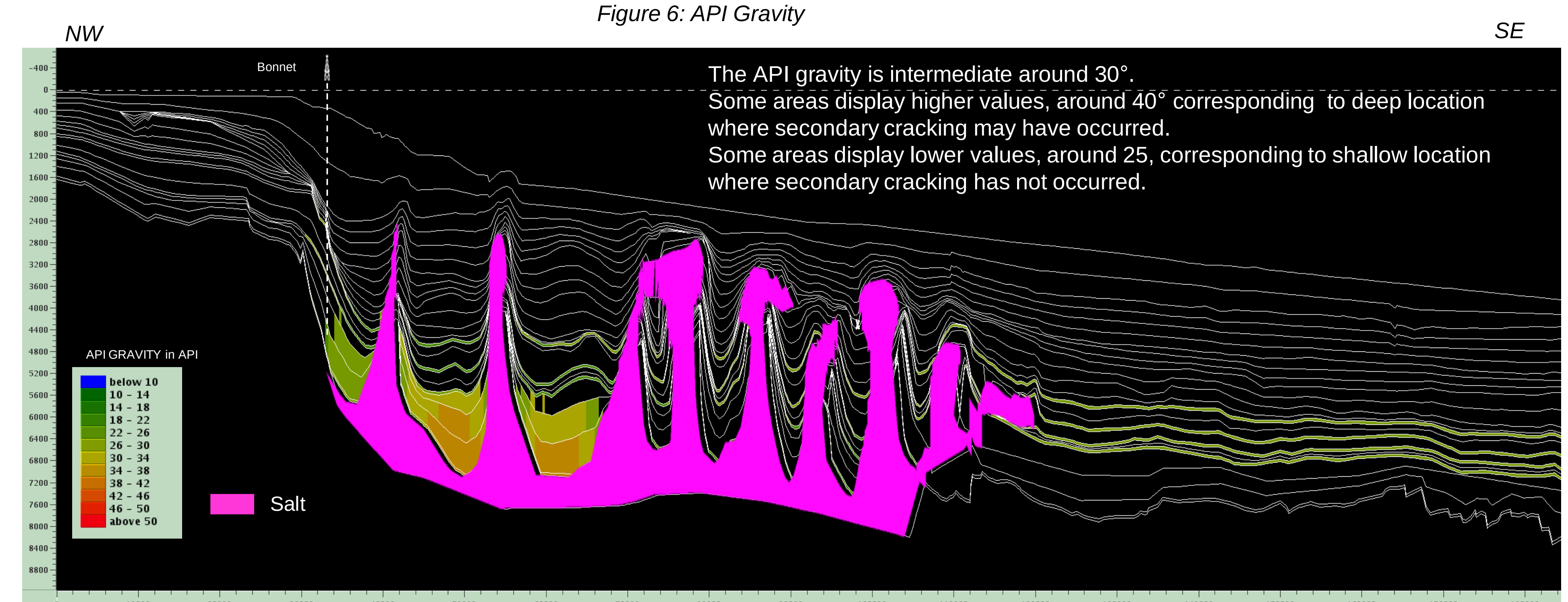


Figure 6: API Gravity



Maturity, HC Fractions and Quality at present day of Section NS1100

CHAPTER 7-2

BASIN MODELING – TEMIS 2D

7-2-3

Section NS 1400 Modeling

BASIN MODELING – TEMIS 2D

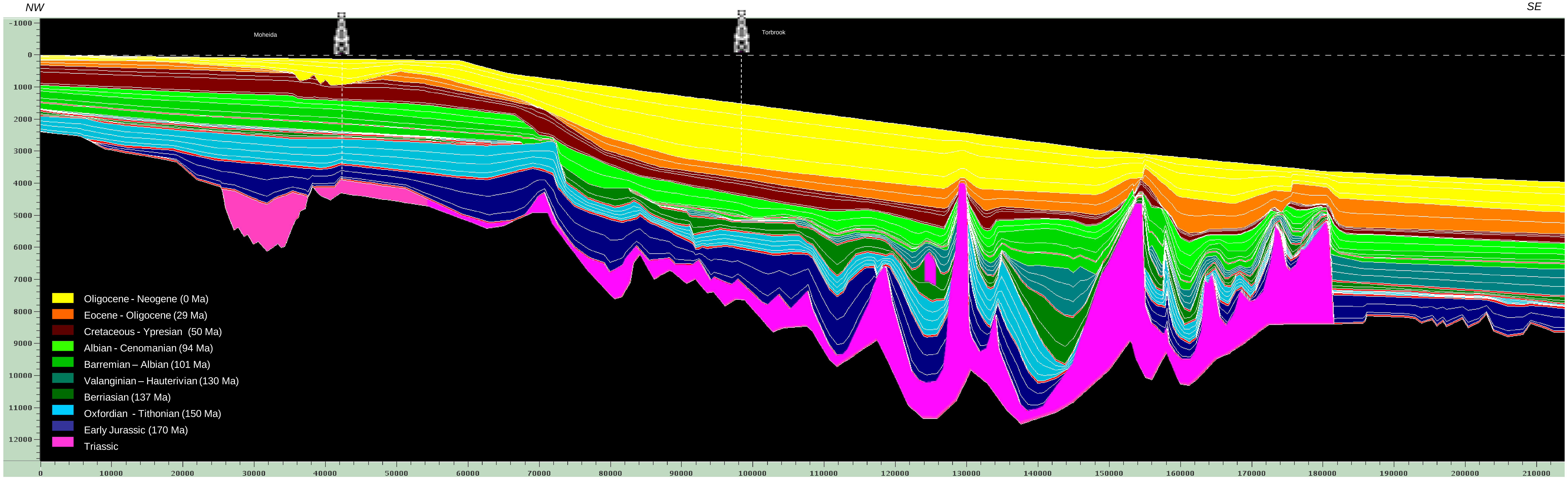


Figure 1: Stratigraphy of the Section NS1400 at Present day

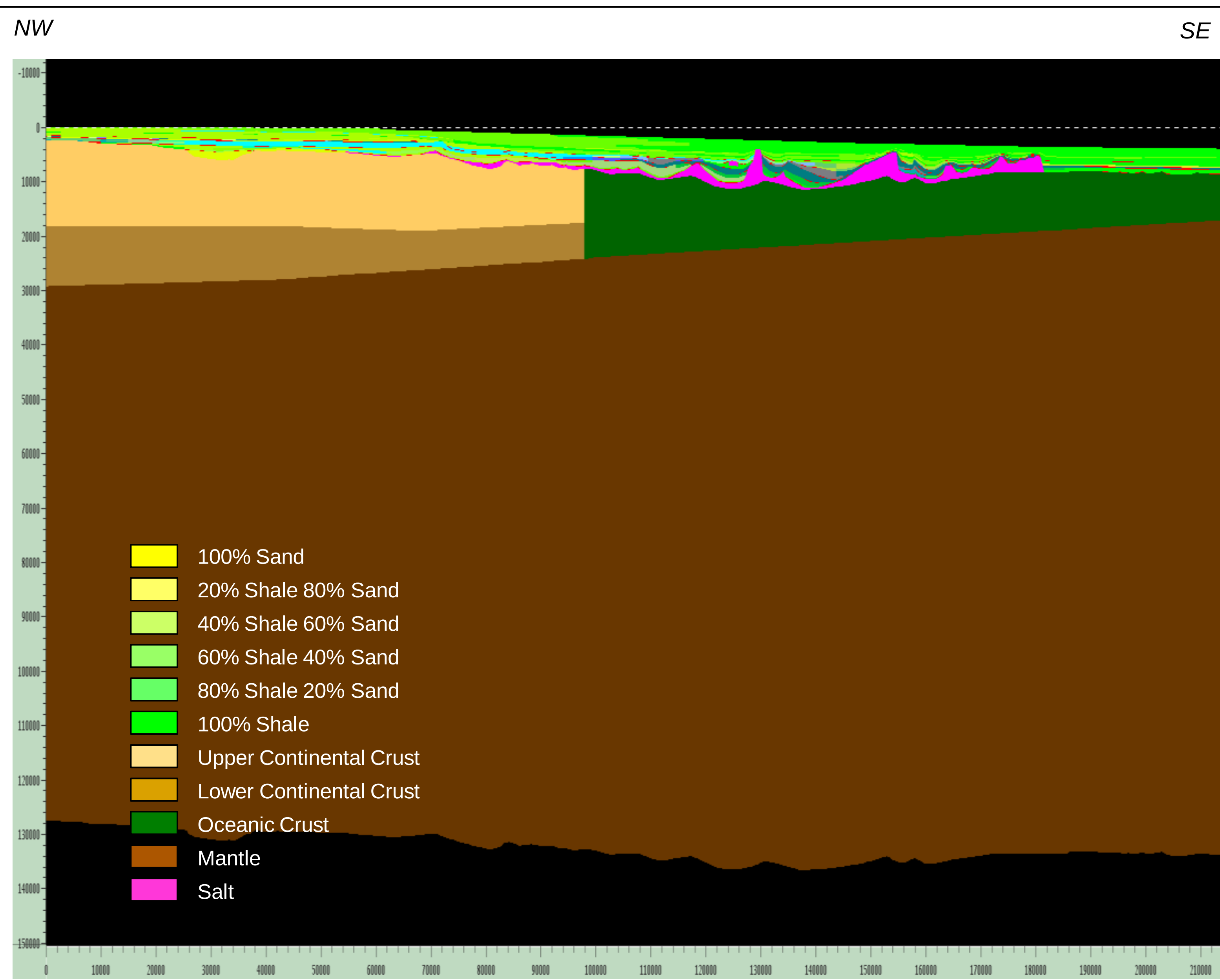


Figure 2: Lithosphere geometry of Section NS1400 at Present day

The limit between continental and oceanic crust domains is at kilometer 95 in the model. The crust maximum thickness of some 30km is located at the north end of the section. The crust minimum thickness of some 8 km (oceanic) is is located at the south end of the section.

The Section NS1400 is 214 kilometers long located at the west of the study domain. The northern part of the section is on the continental platform. The southern part is in the oceanic domain from kilometer 95 on.

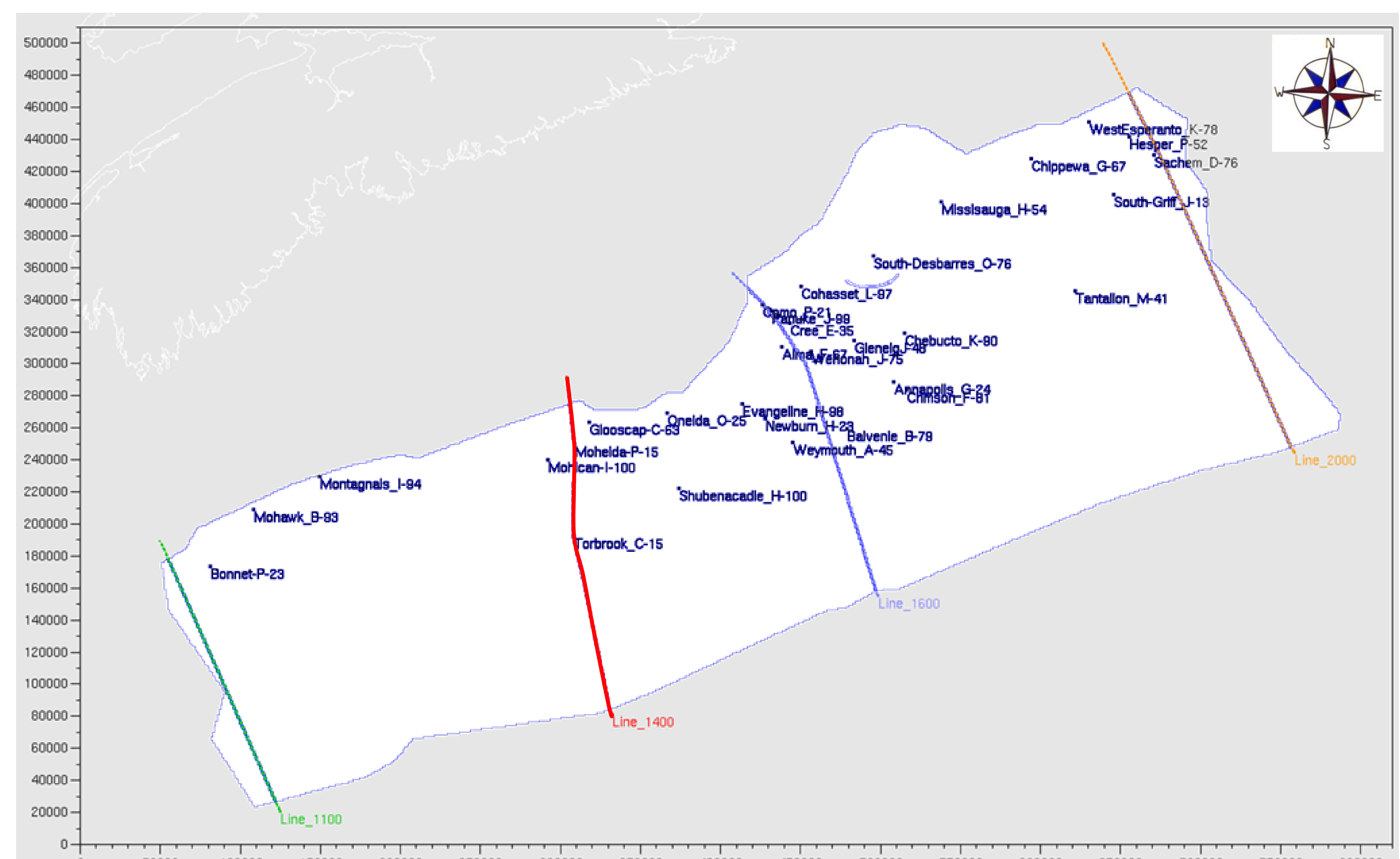


Figure 3: Location of Section NS1400 on Map

PL. 7-2-3-1a **Stratigraphy, Basement geometry and Location Map of Section NS1400**

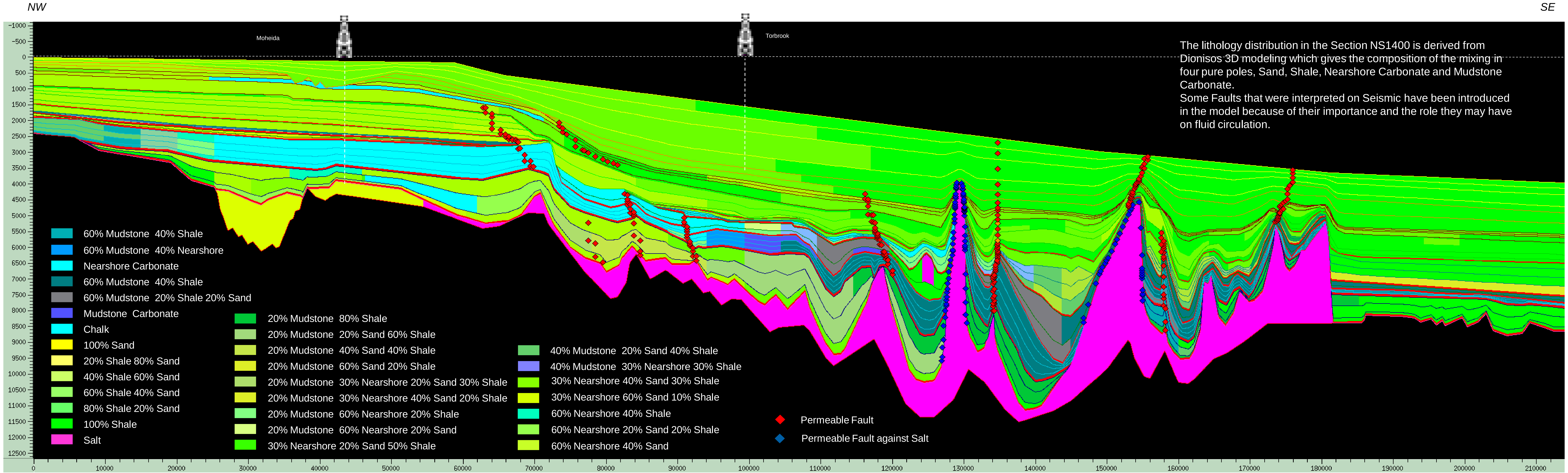


Figure 1: Lithology and Fault zones of Section NS1400 at Present day

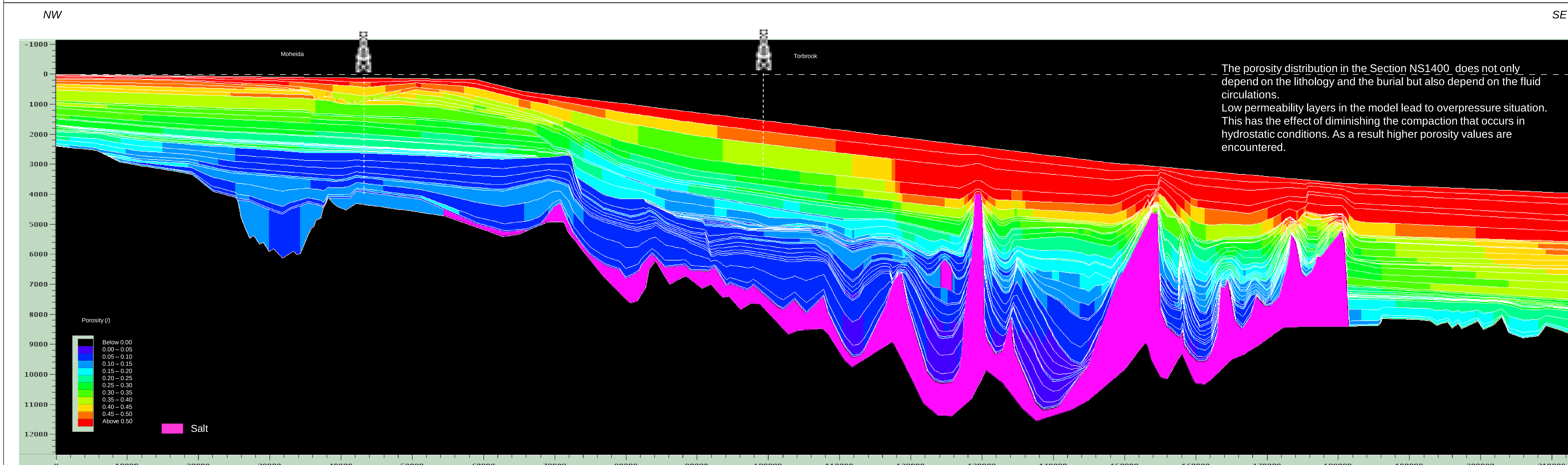


Figure 2: Porosity of Section NS1400 at Present day

BASIN MODELING – TEMIS 2D

PLAY FAIRWAY ANALYSIS - OFFSHORE NOVA SCOTIA - CANADA – June 2011

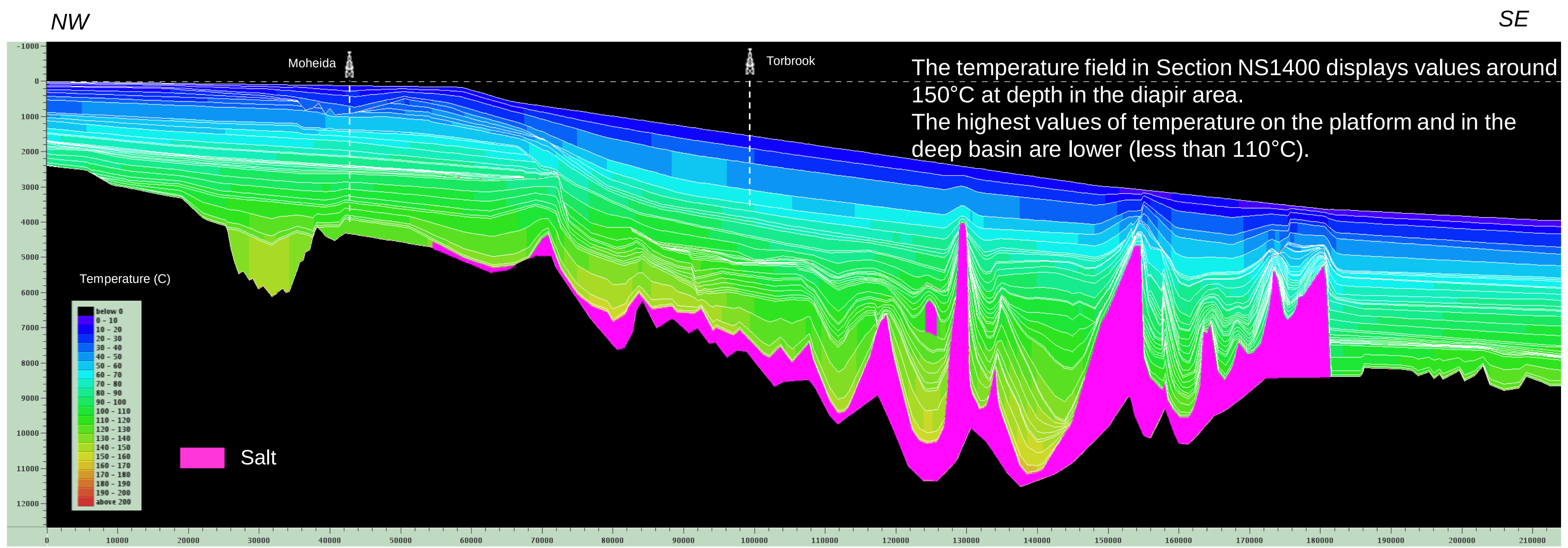
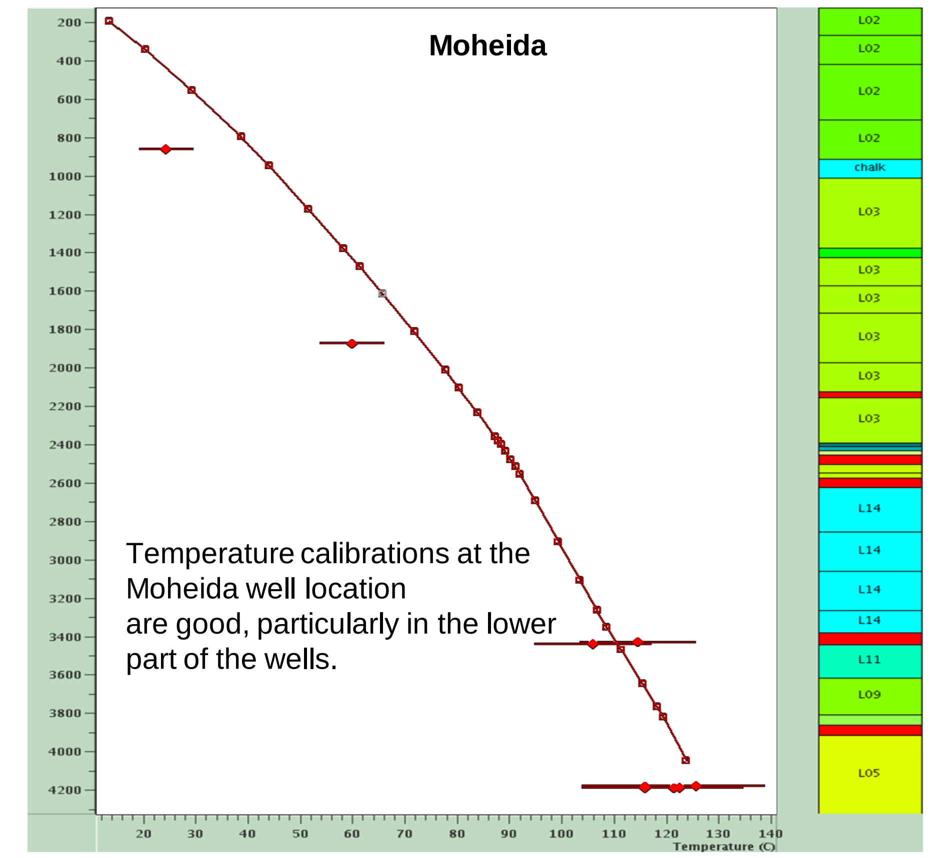


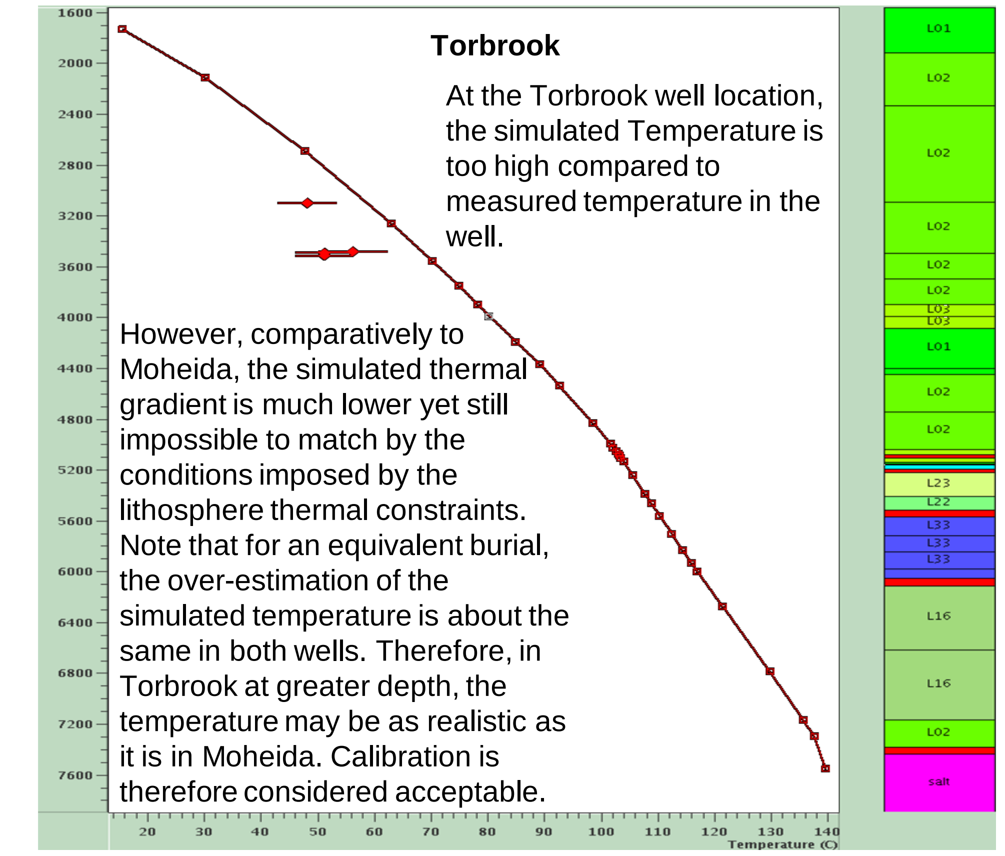
Figure 1: Temperature Field

Temperature Calibration

Modeled curve

Measured values in Well





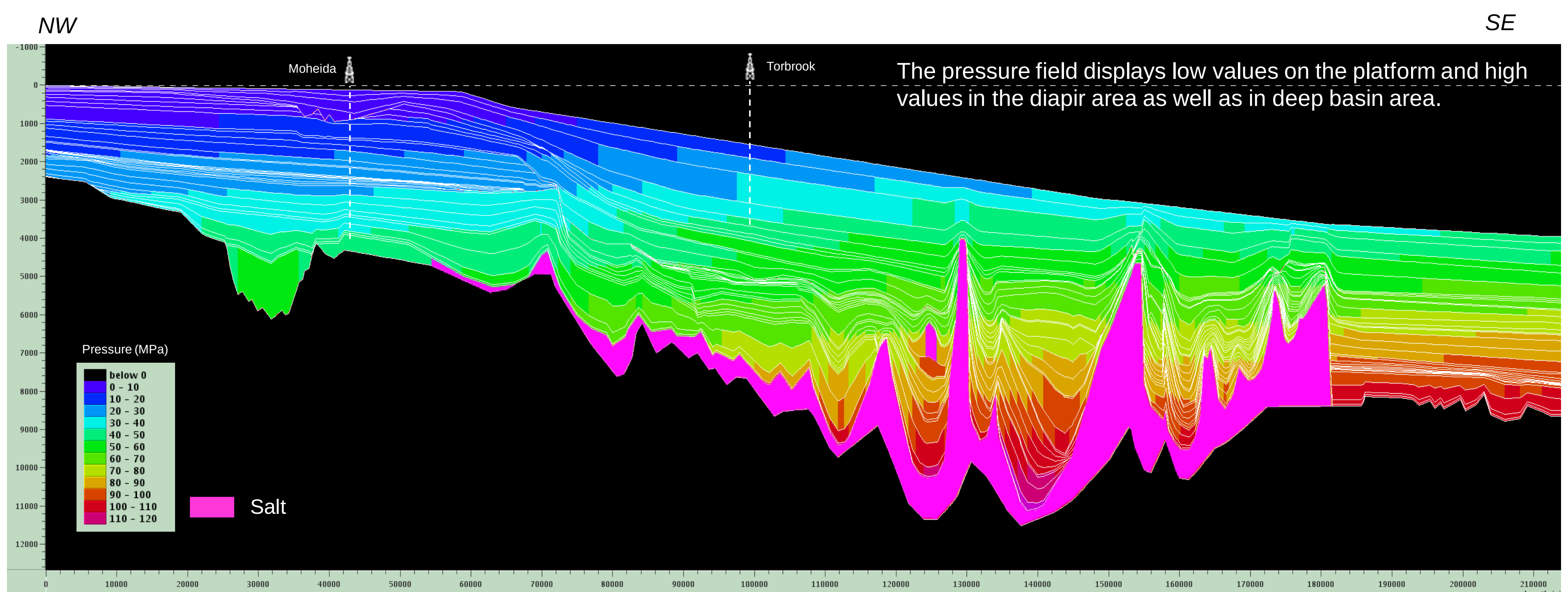
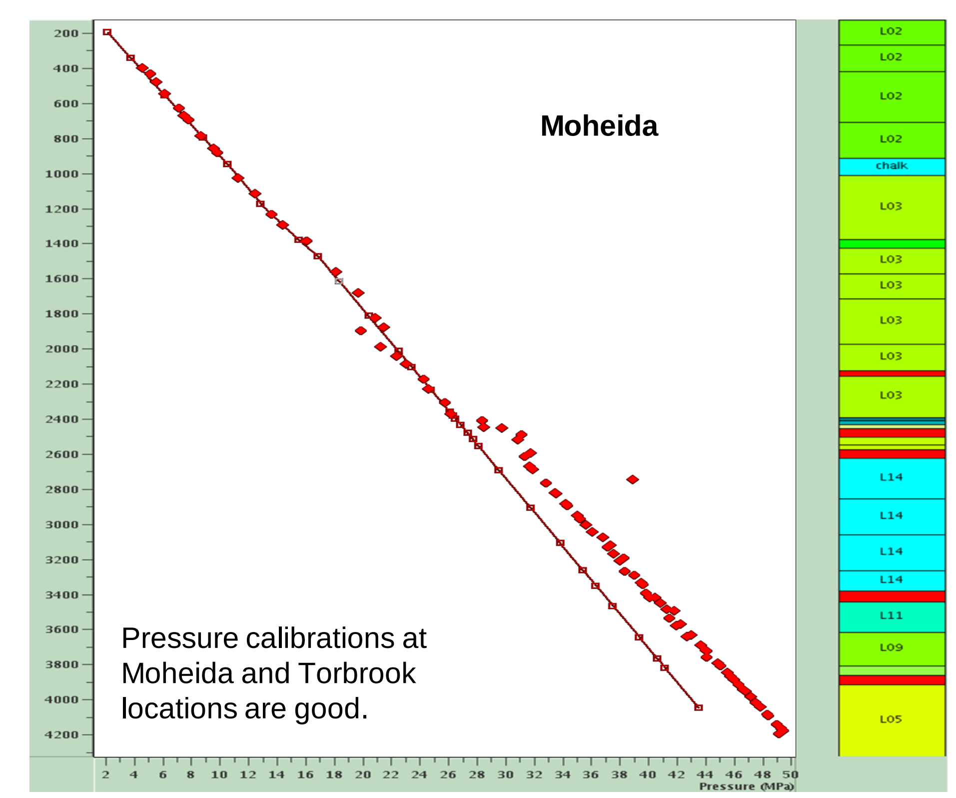


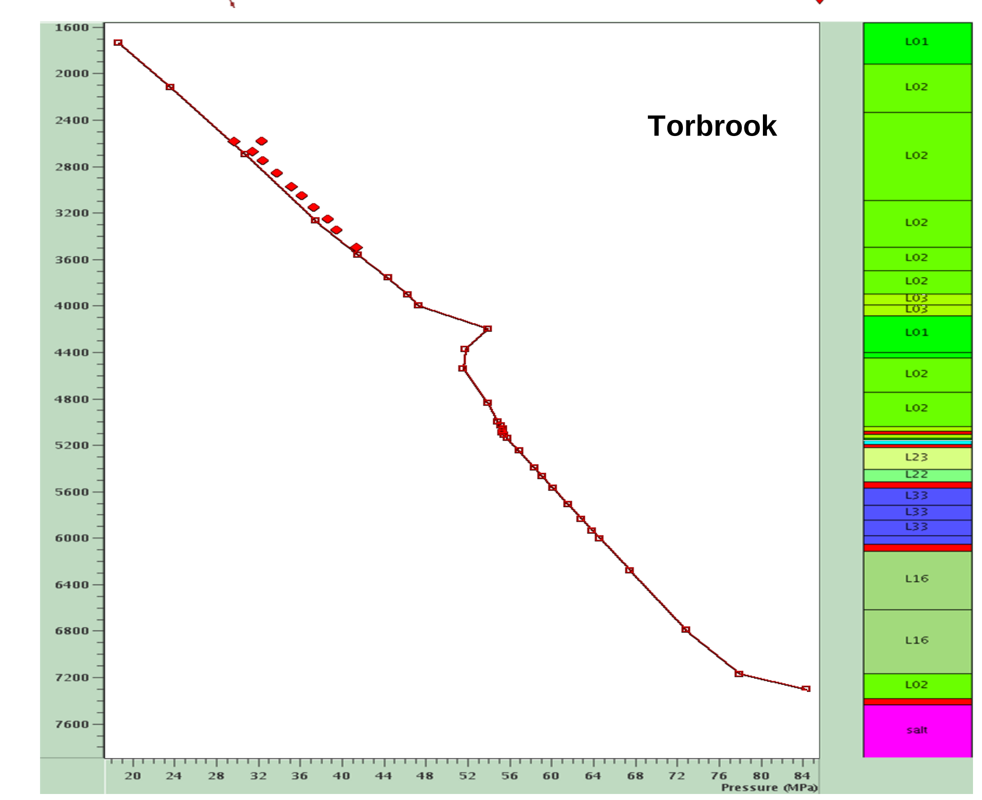
Figure 2: Pressure Field

Pressure Calibration

Modeled curve

Measured values in Well





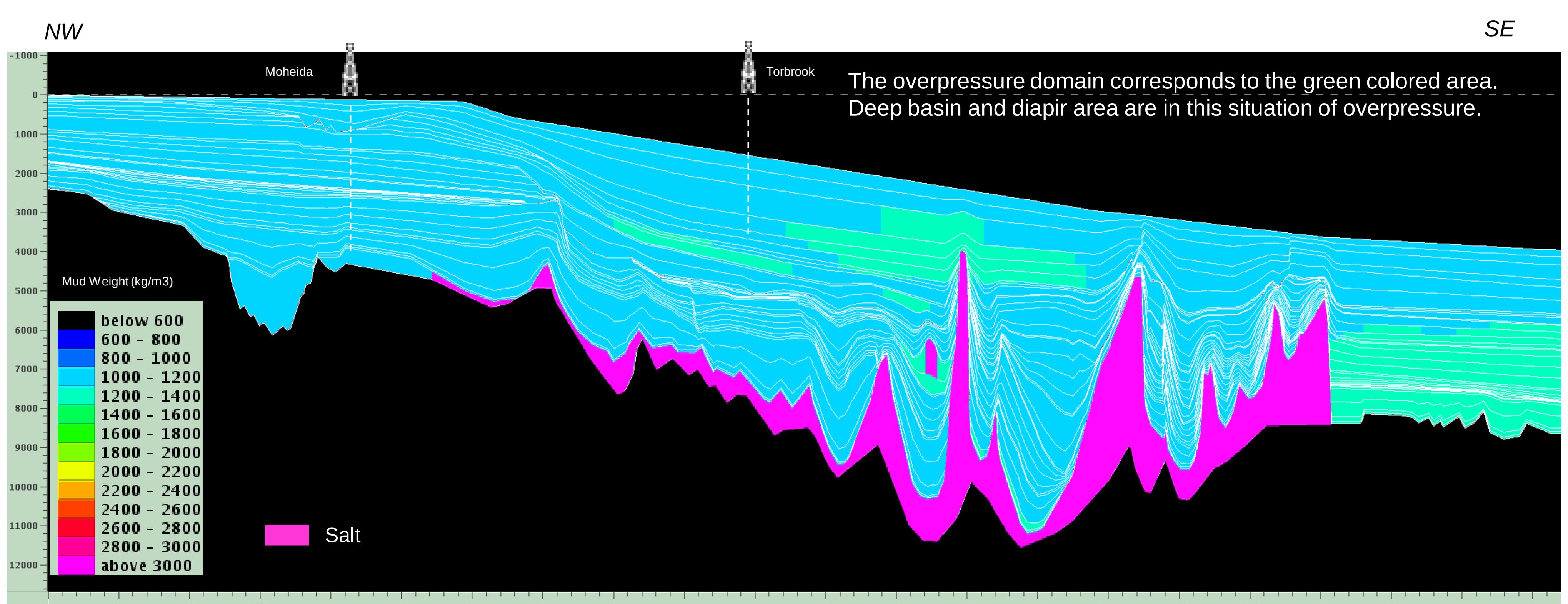
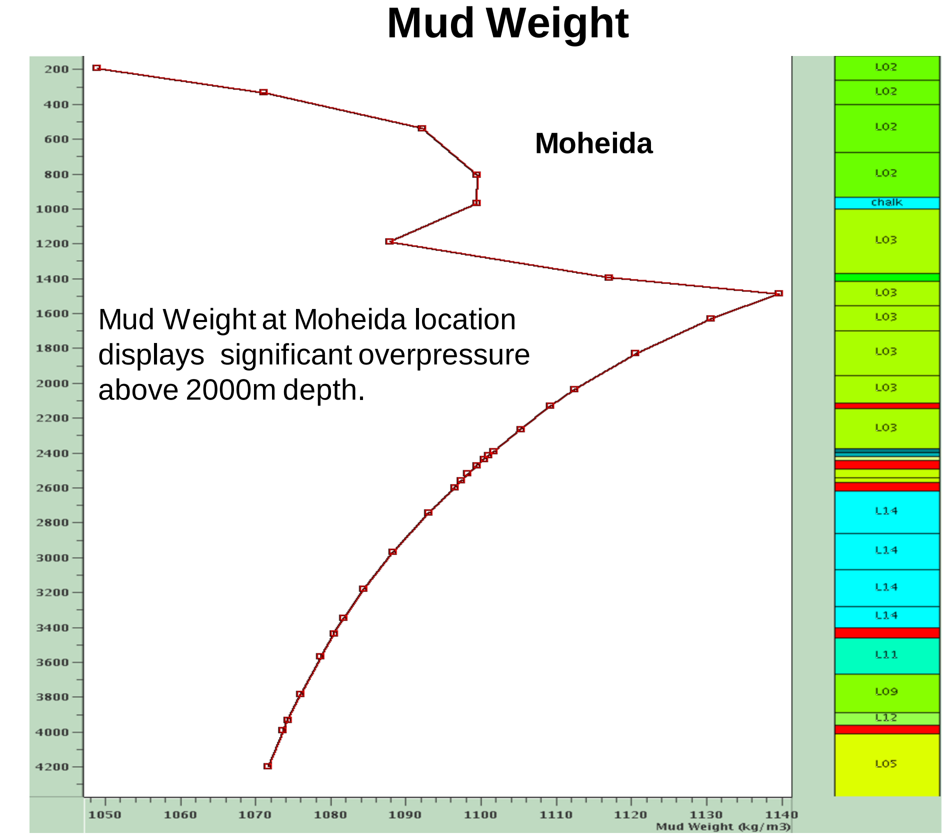
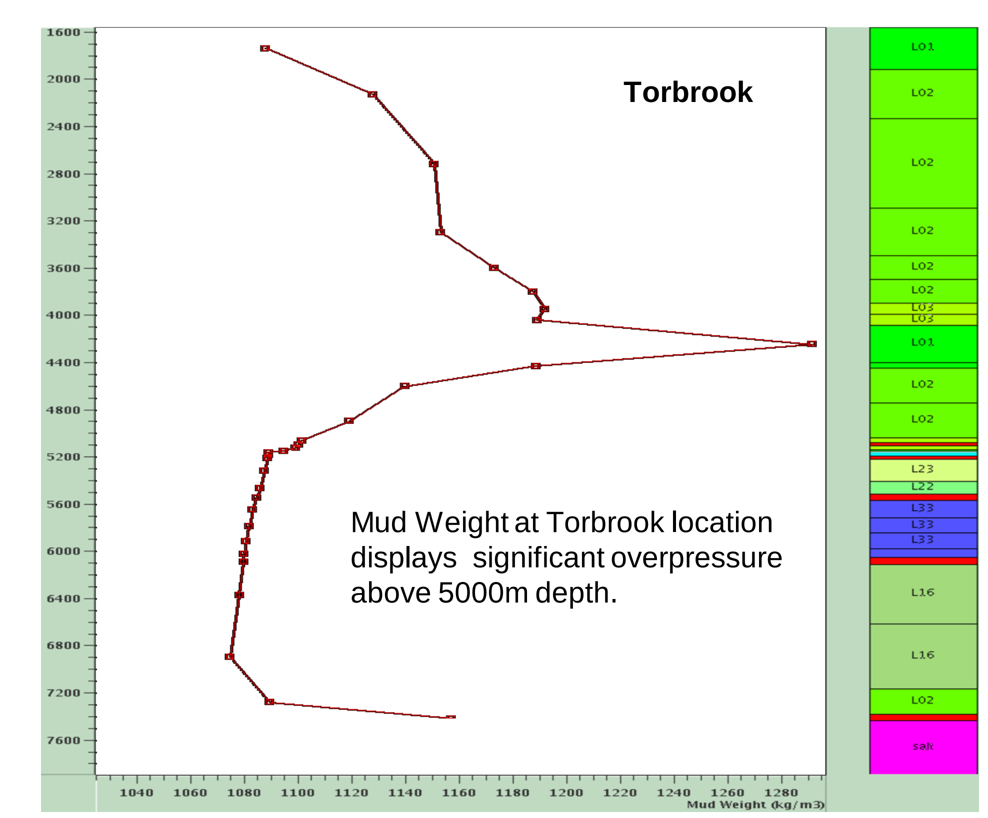


Figure 3: Mud Weight Field

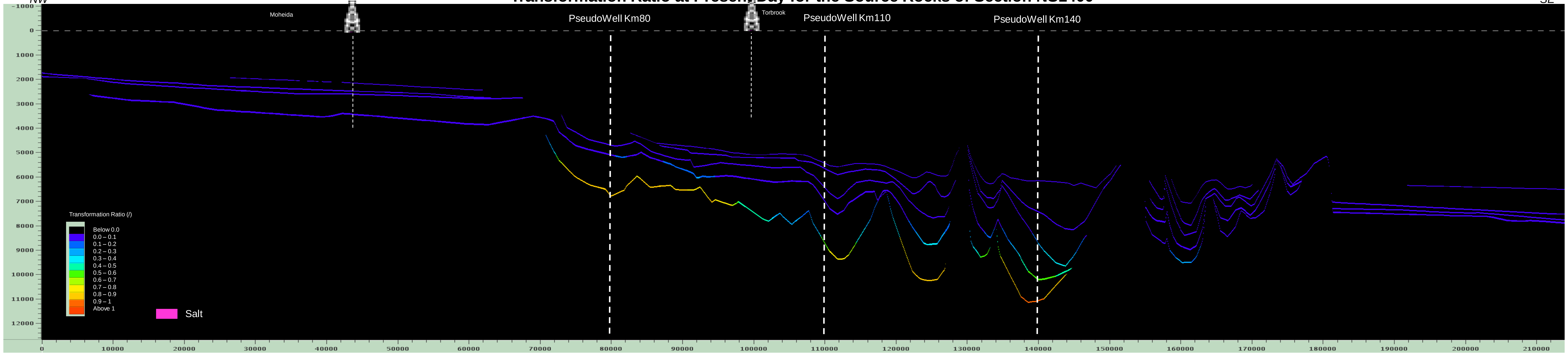
Mud Weight



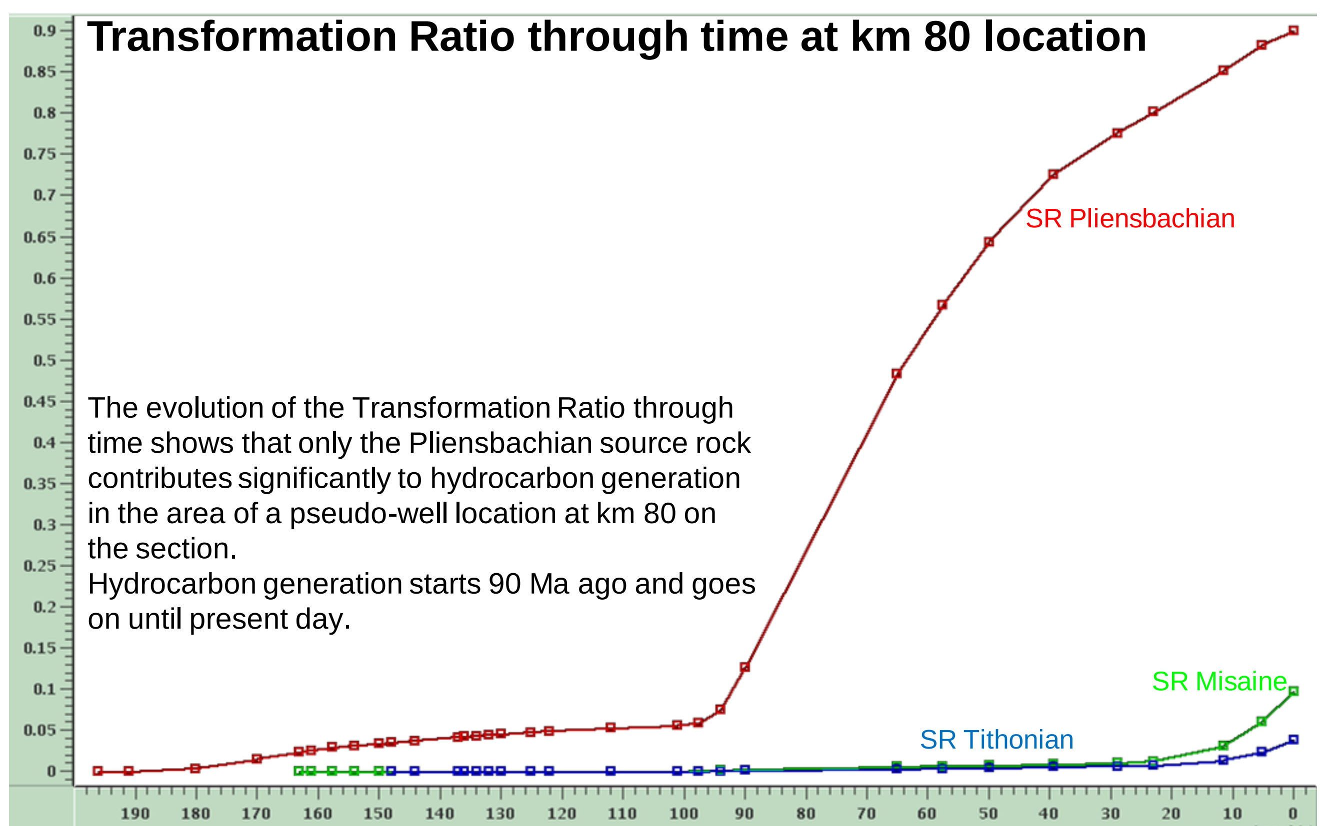


PL. 7-2-3-2a **Thermodynamic Fields an Calibration of Section NS1400**

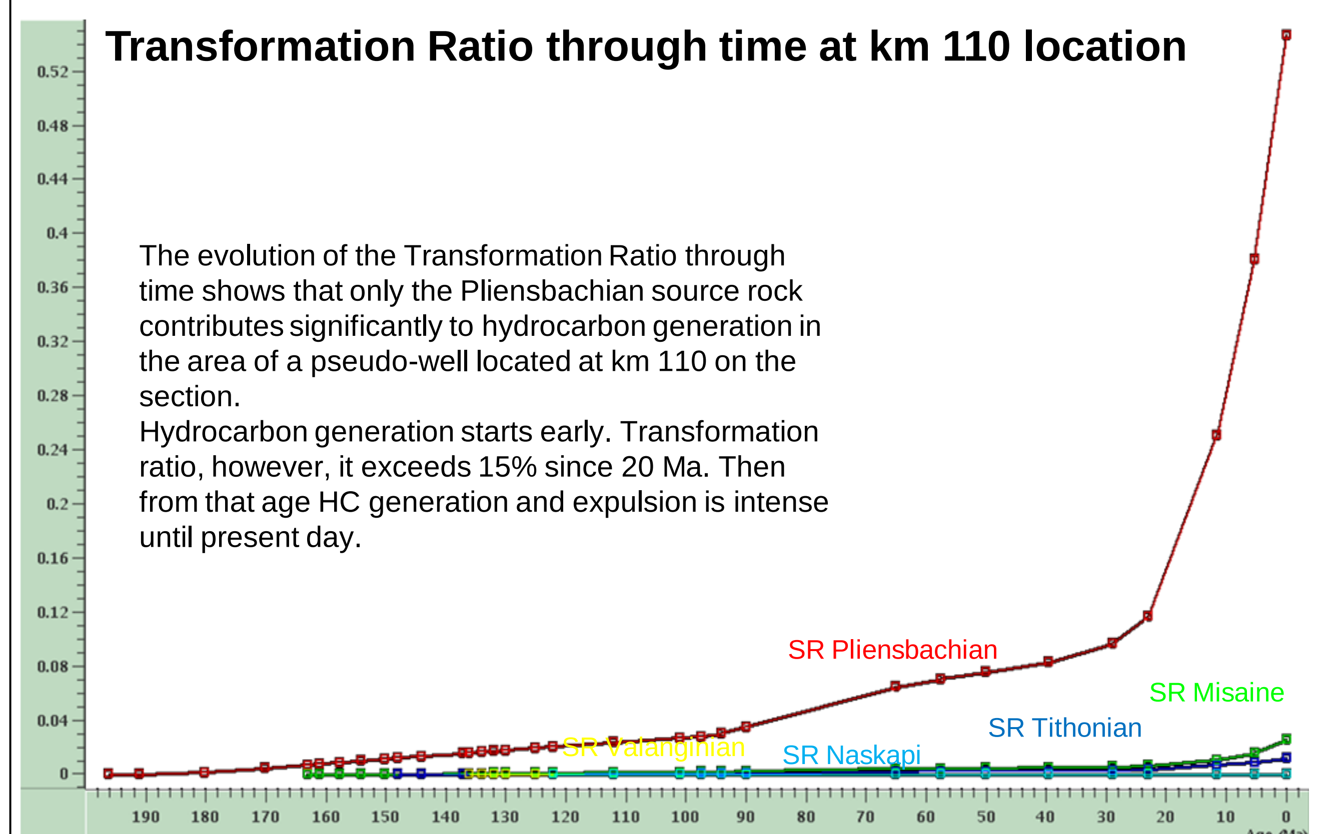
Transformation Ratio at Present Day for the Source Rocks of Section NS1400



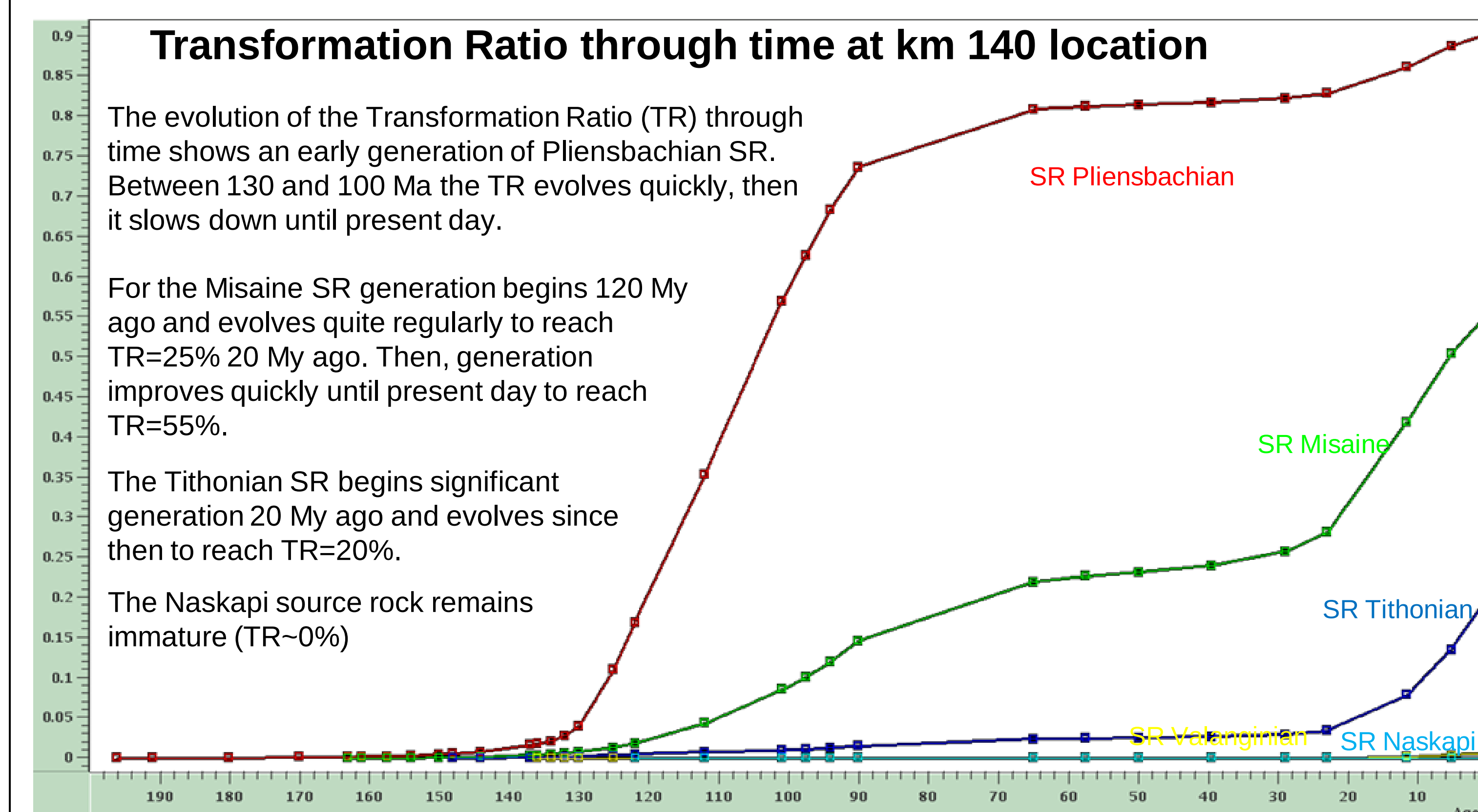
Transformation Ratio through time at km 80 location



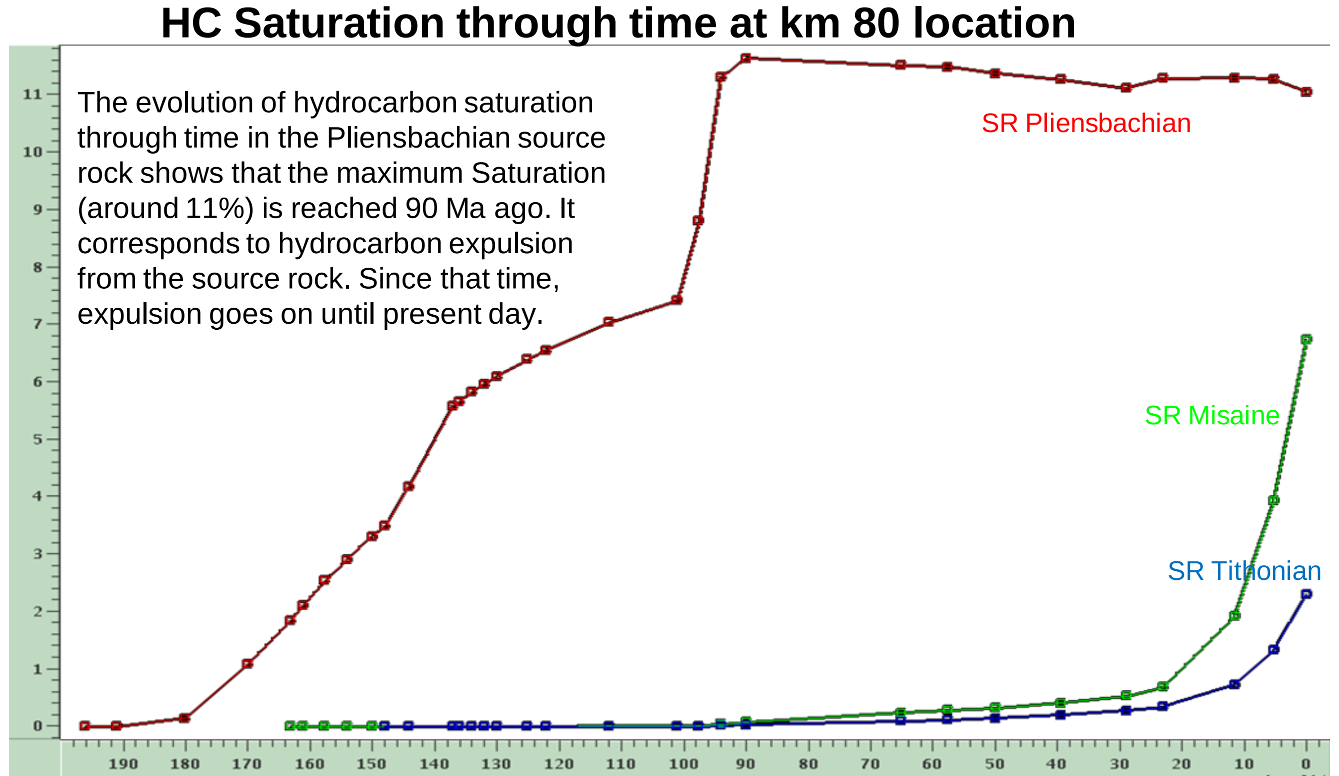
Transformation Ratio through time at km 110 location



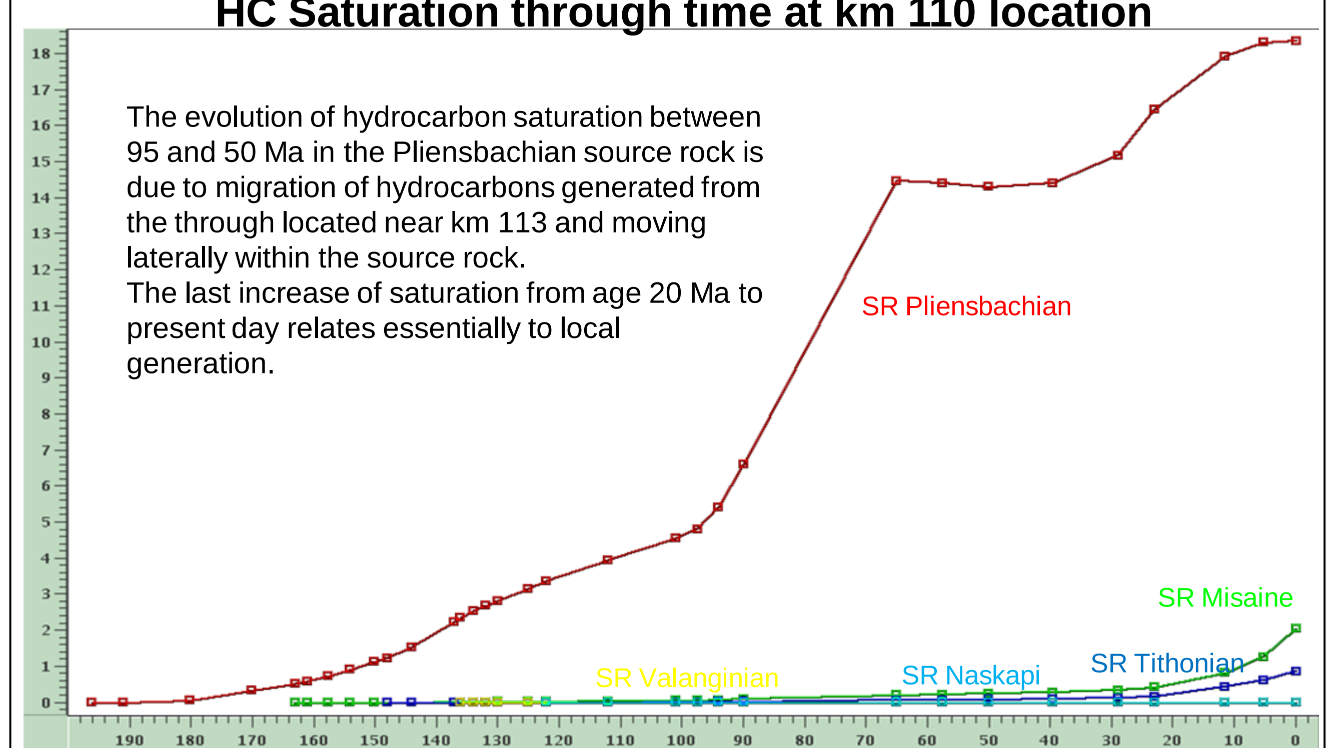
Transformation Ratio through time at km 140 location



HC Saturation through time at km 80 location



HC Saturation through time at km 110 location



HC Saturation through time at km 140 location

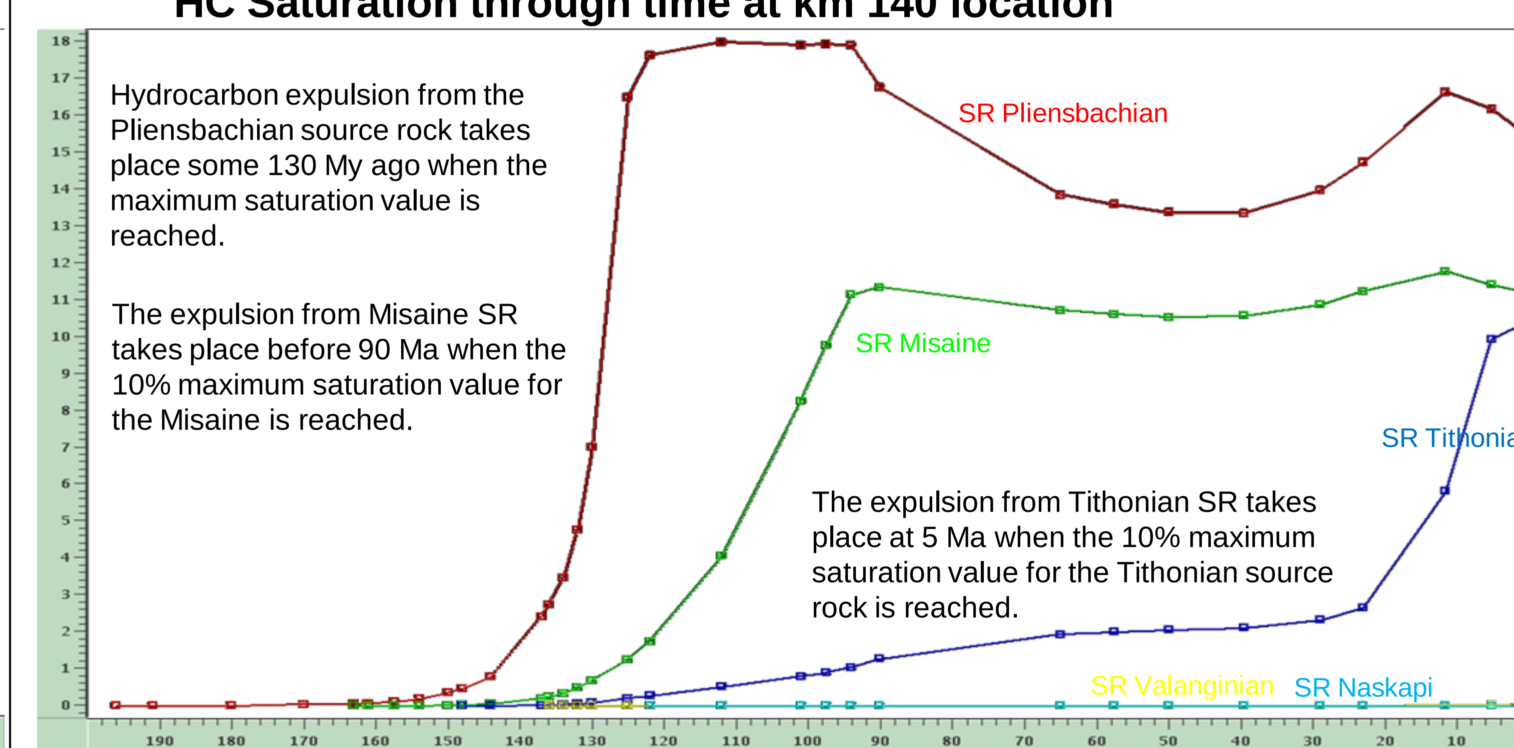


Figure 1: Turonian – 90 Ma

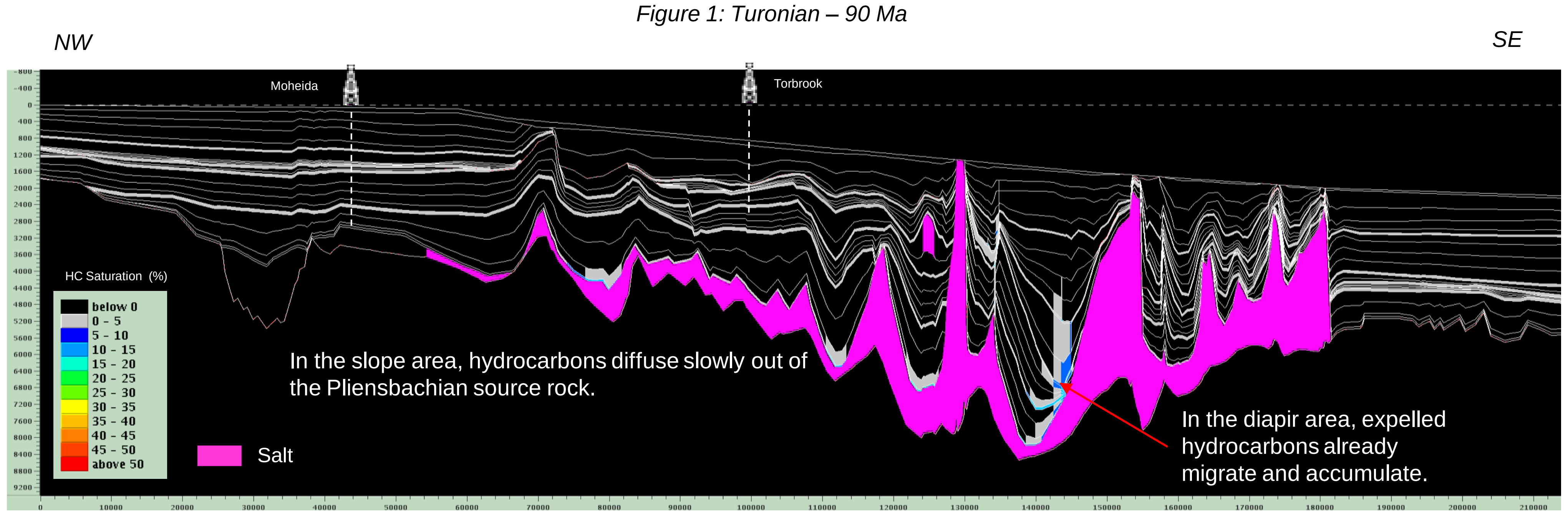


Figure 2: Ypresian - 50 Ma

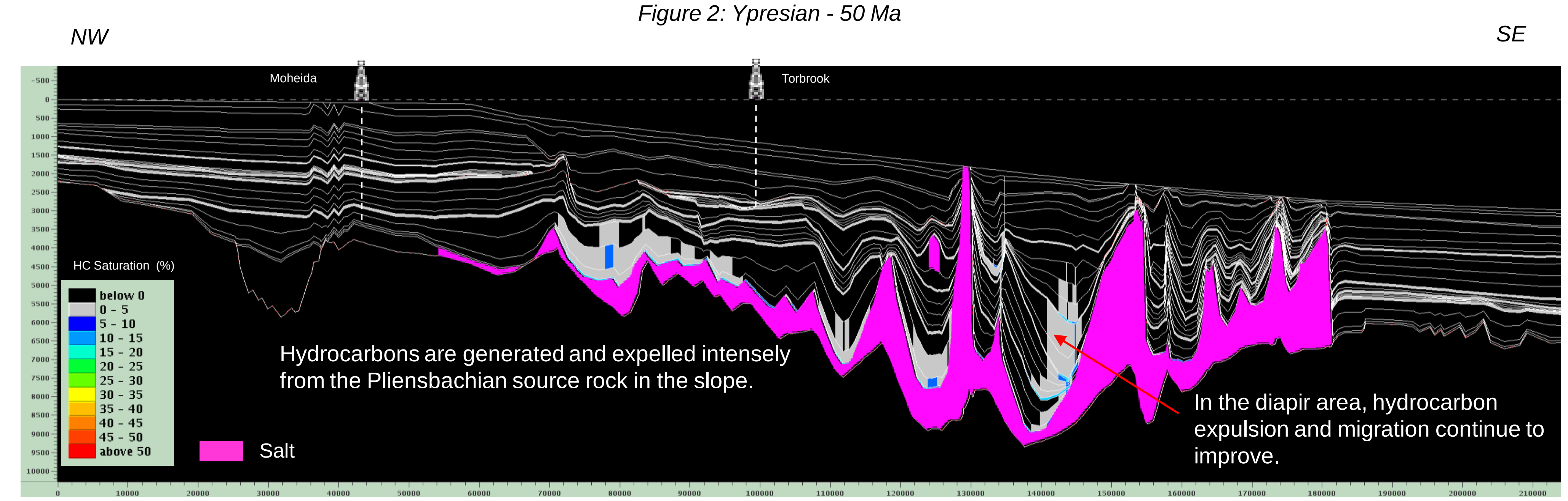


Figure 3: Chattian - 23 Ma

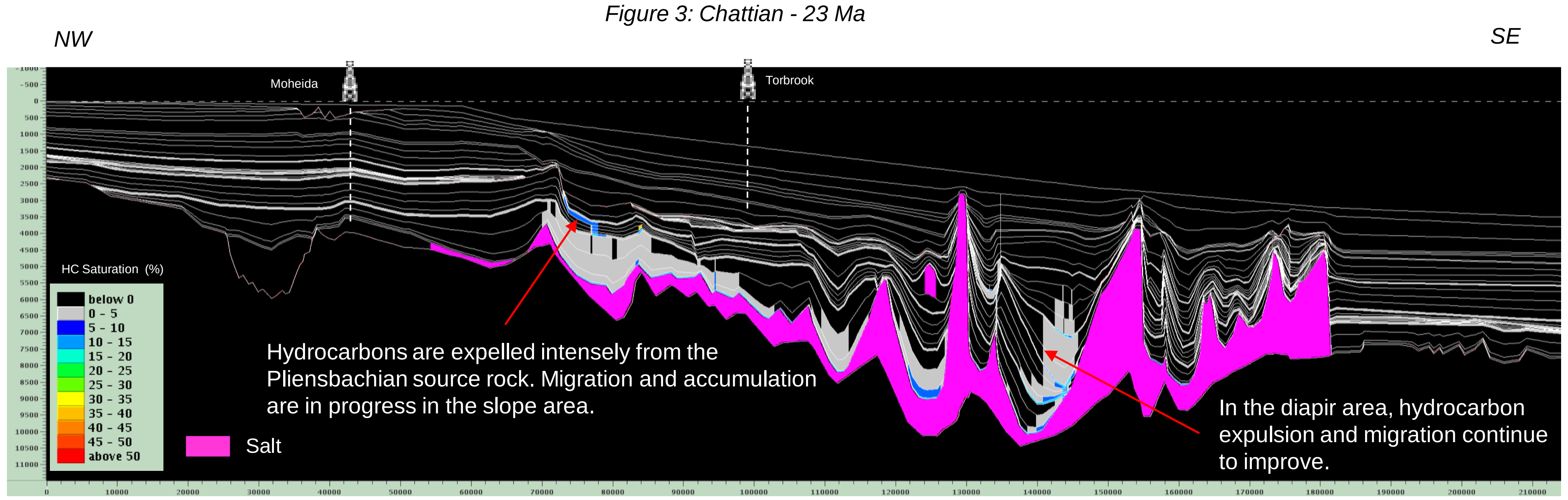


Figure 4: Serravallian – 11.6 Ma

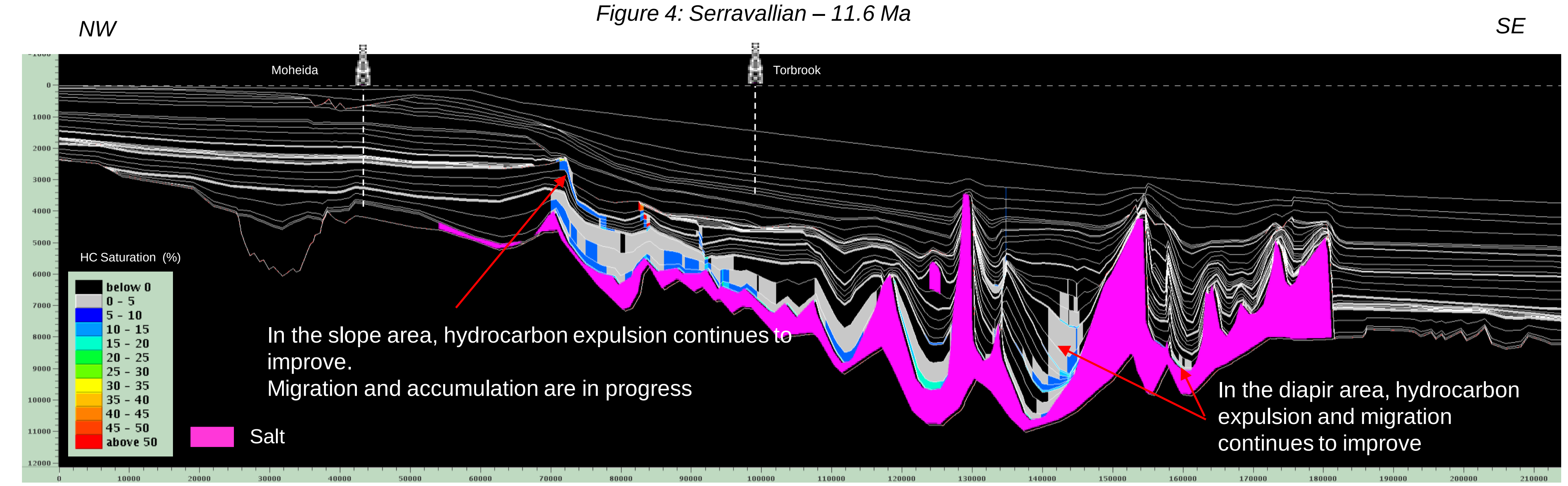
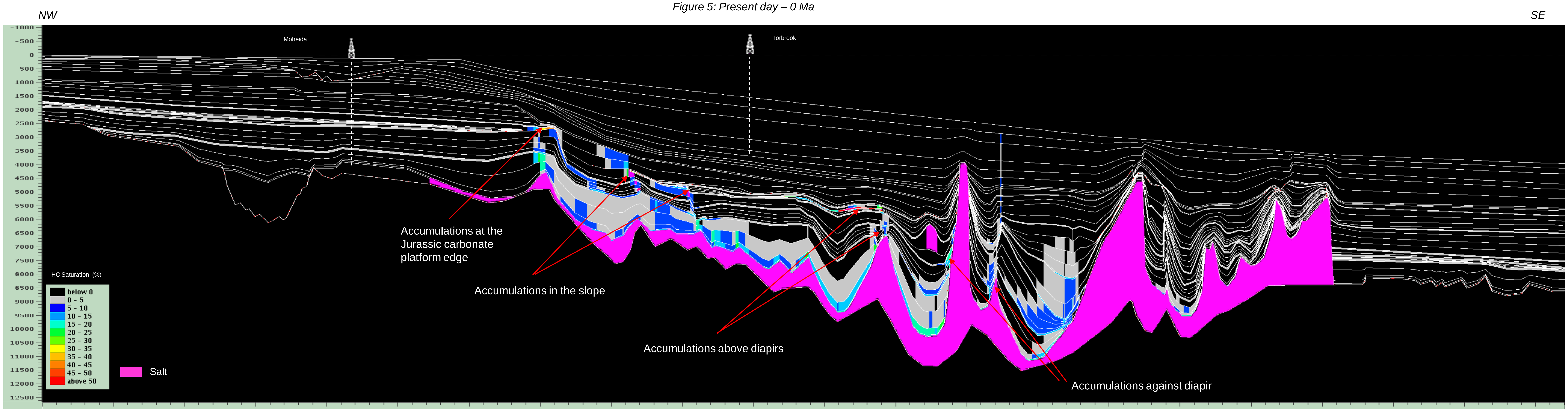


Figure 5: Present day – 0 Ma



PL. 7-2-3-3a **HC Saturation through time of Section NS 1400**

Figure 1: R0 Maturity

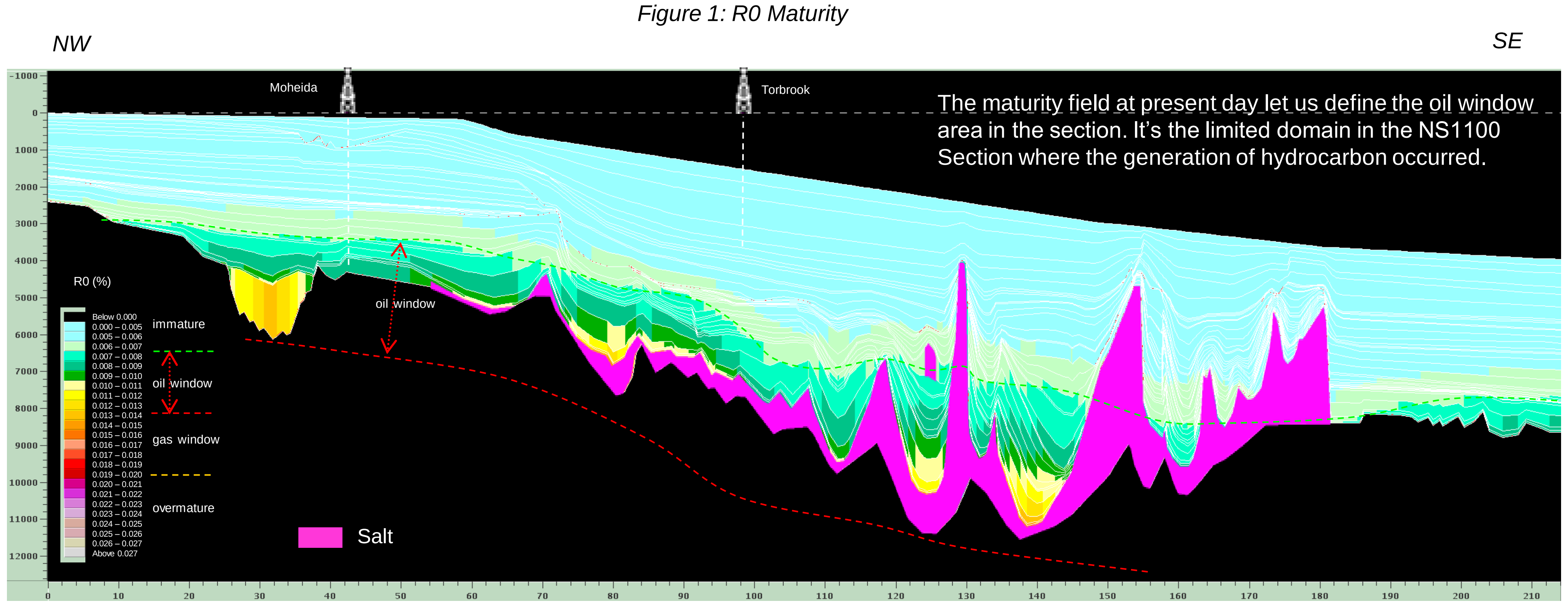


Figure 2: Total HC Mass

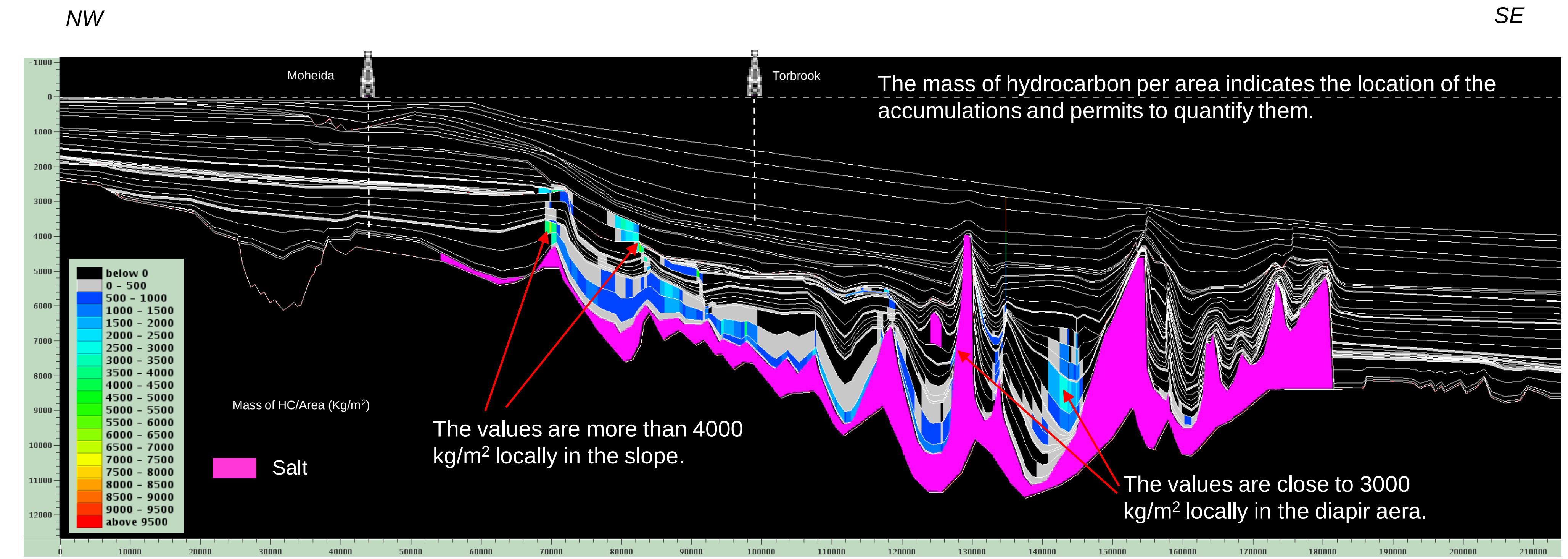


Figure 3: Fraction C1-C5

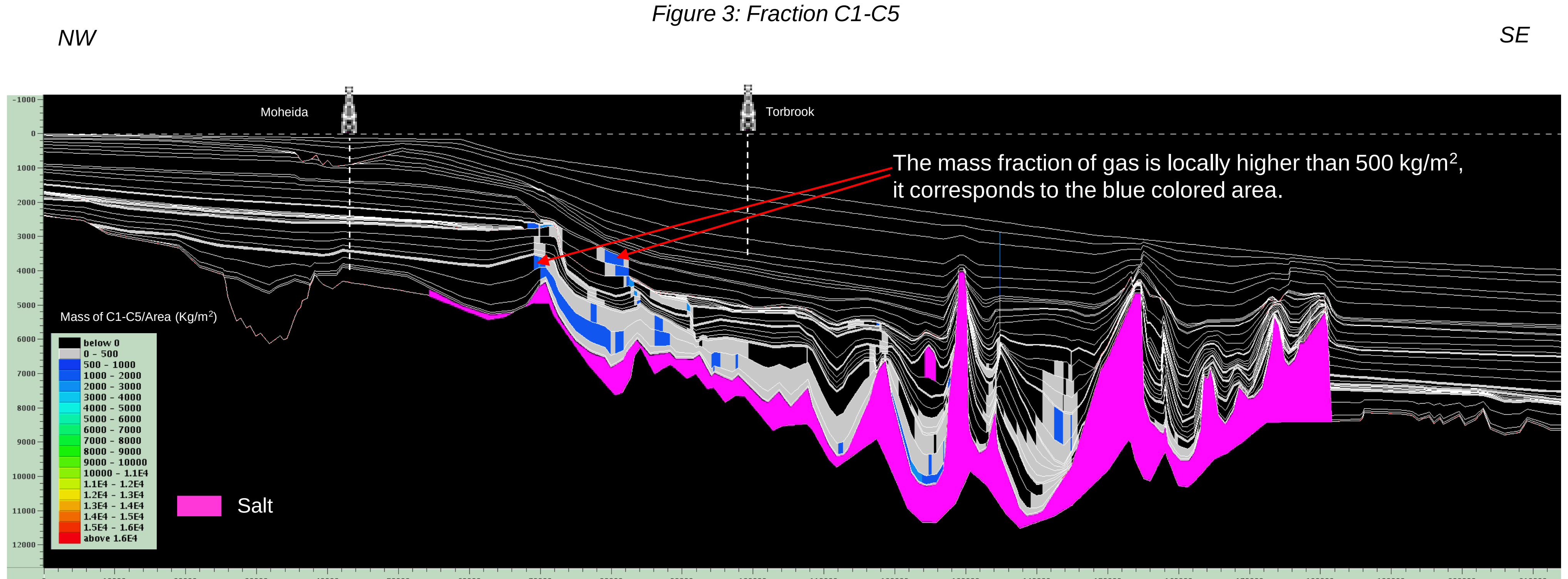


Figure 4: Fraction C6-C13

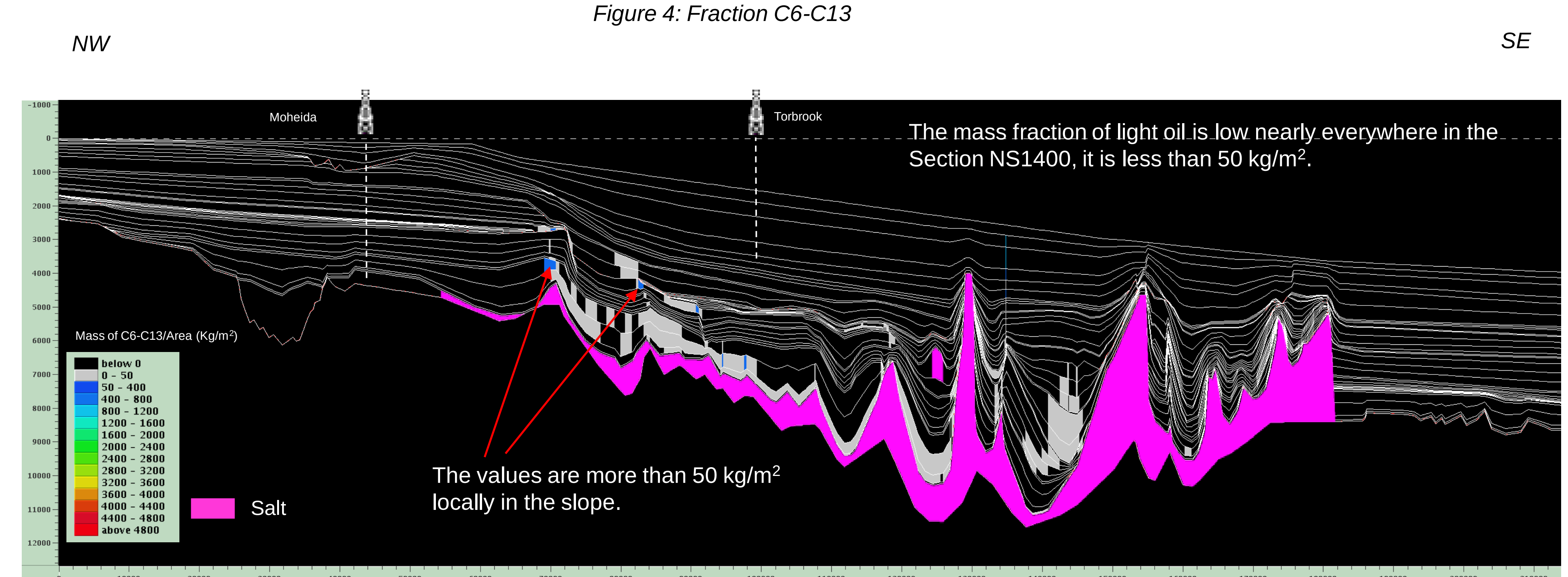


Figure 5: Fraction Nitrogen / Sulfur / Oxygen OIL

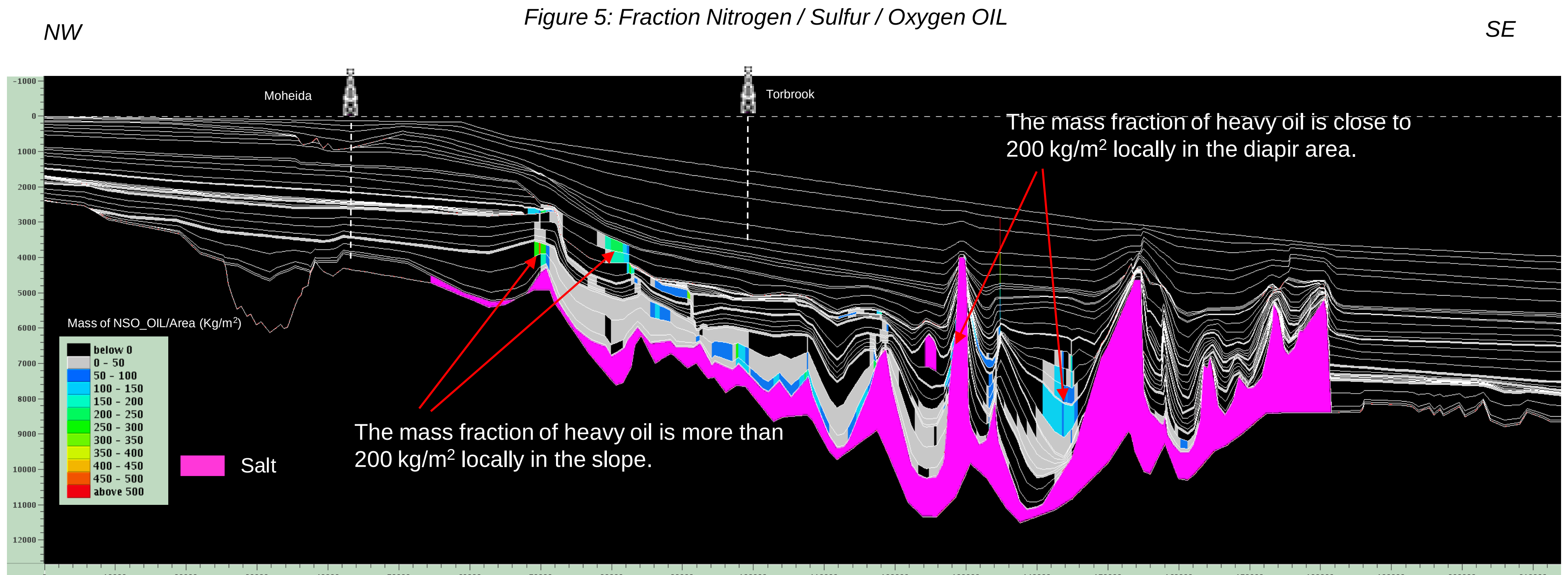
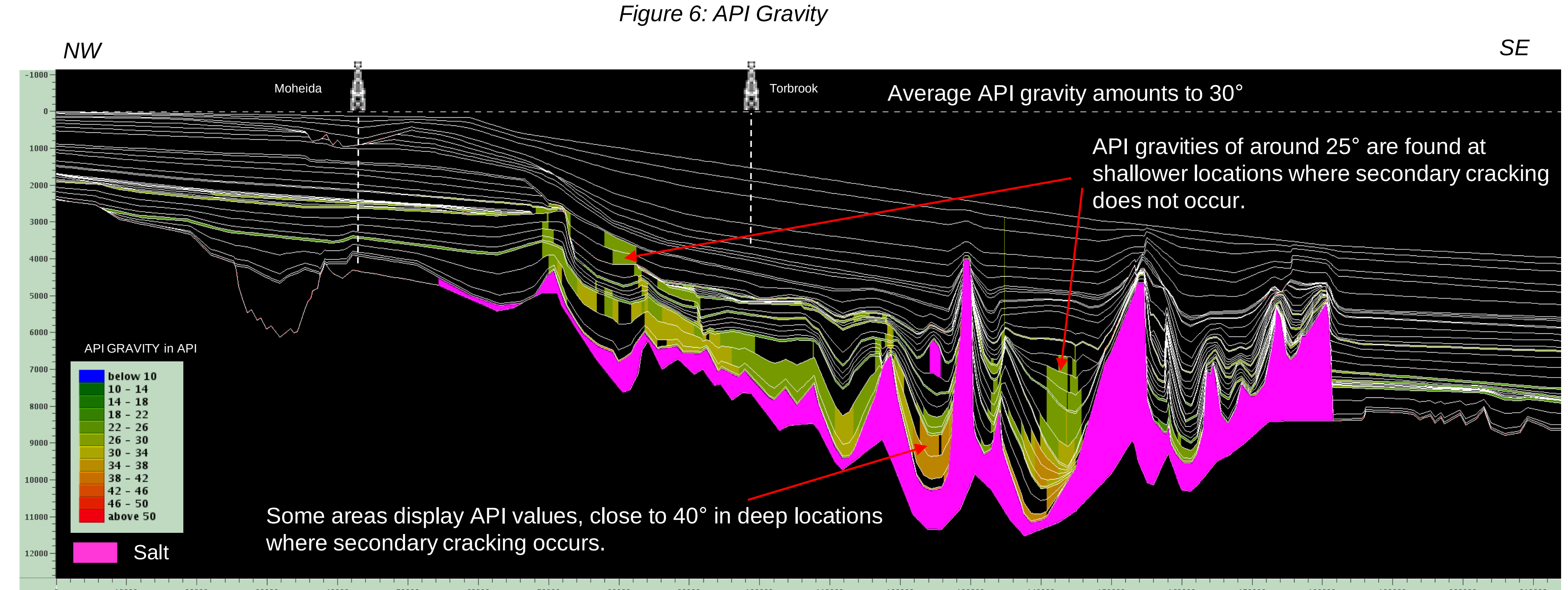


Figure 6: API Gravity



Maturity, Fractions and HC Quality at present day of Section NS1400

CHAPTER 7-2

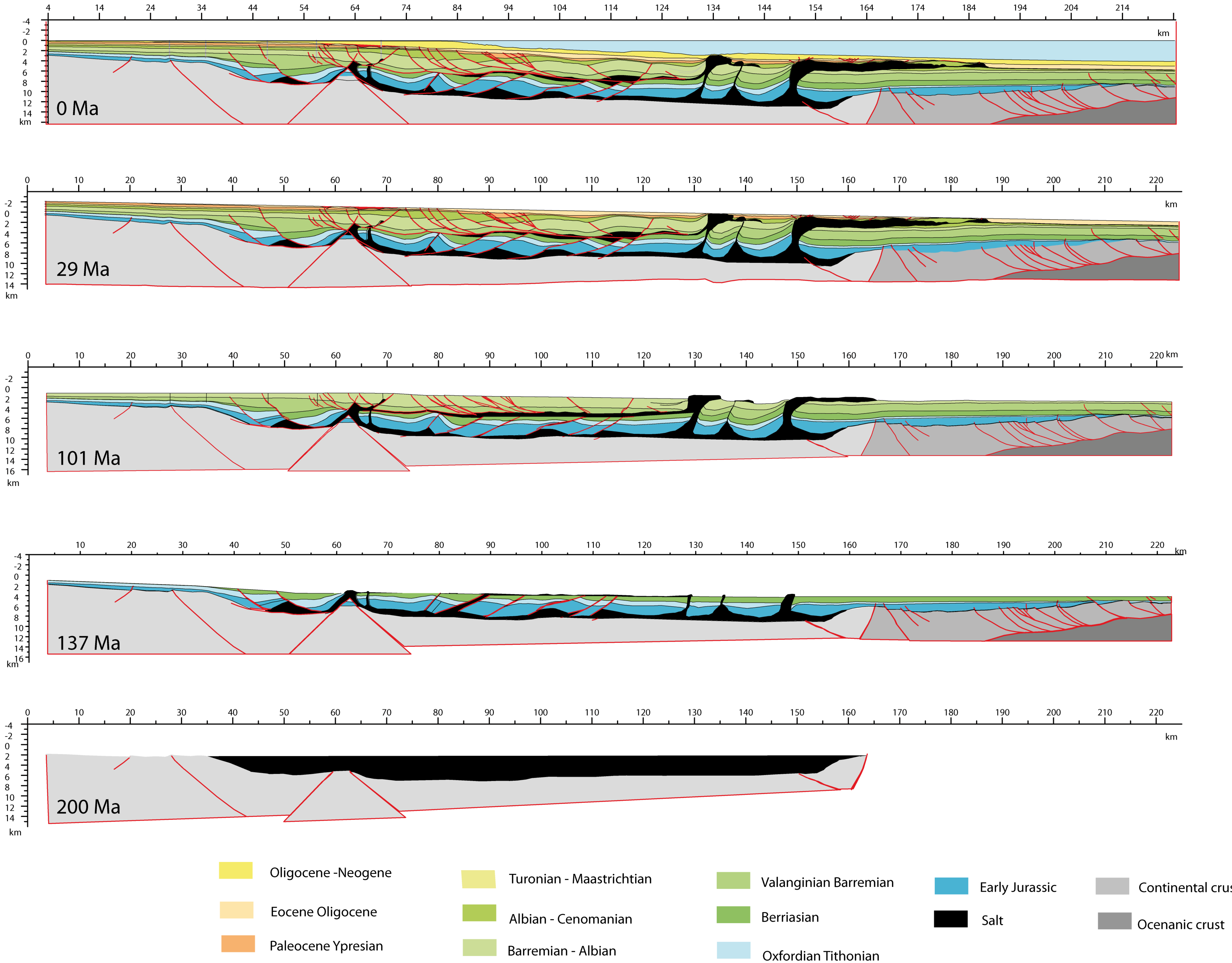
BASIN MODELING – TEMIS 2D

7-2-4

Section NS 1600 Modeling

BASIN MODELING – TEMIS 2D

PLAY FAIRWAY ANALYSIS - OFFSHORE NOVA SCOTIA - CANADA – June 2011



Restoration of Section NS1600

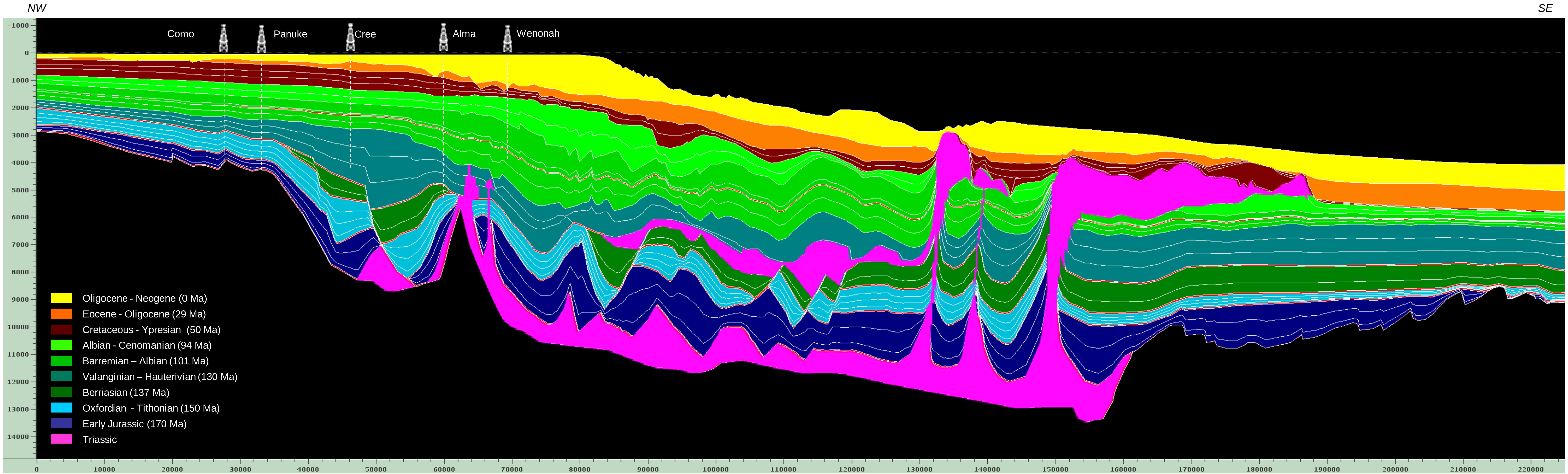


Figure 1: Stratigraphy of the Section NS1600 at Present day

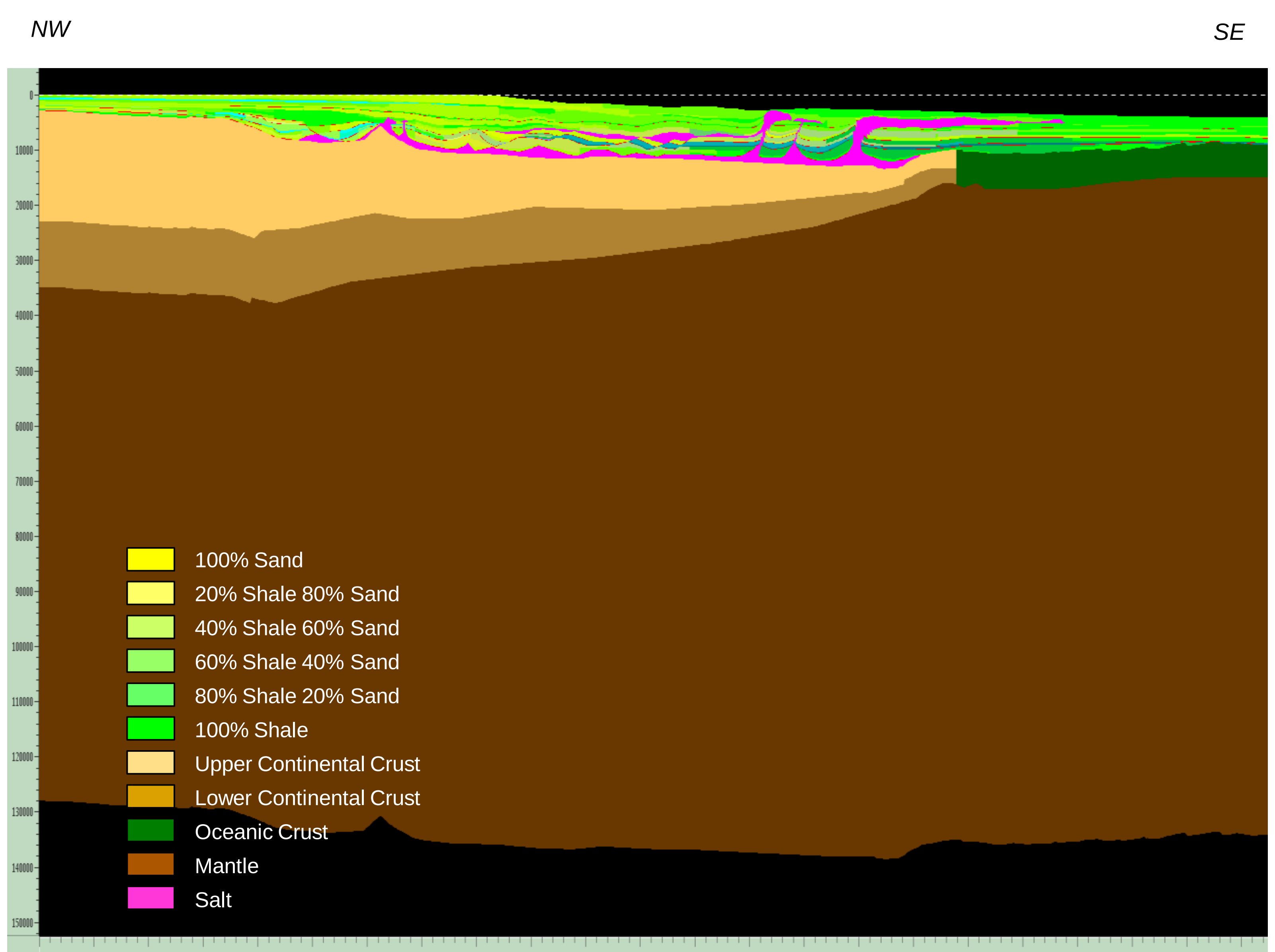


Figure 2: Lithosphere geometry of Section NS1600 at Present day

In the model, the limit between continental and oceanic crust domains is fixed at kilometer 170.
The crust maximum thickness of 35 km is located at the north end of the section. The crust thickness is minimum (8km thick) and oceanic at the south end of the section.

The Section NS1600 is 225 kilometers long located in the center of the study area.
The northern part of the section is continental and intermediate. From km 170, the southern part is oceanic.

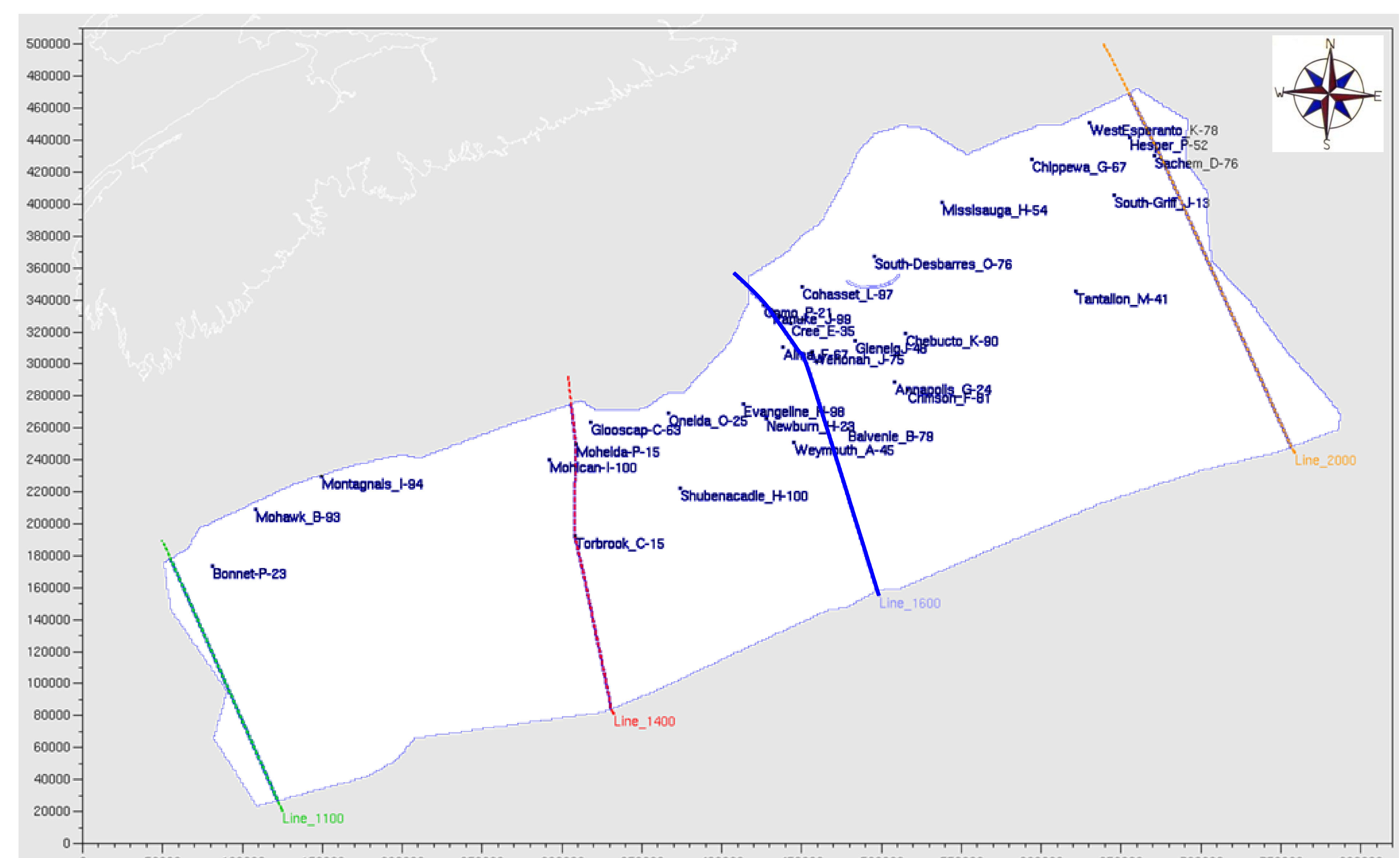


Figure 3: Location of Section NS1600 on Map

Stratigraphy, Basement geometry and Location Map - Section NS1600

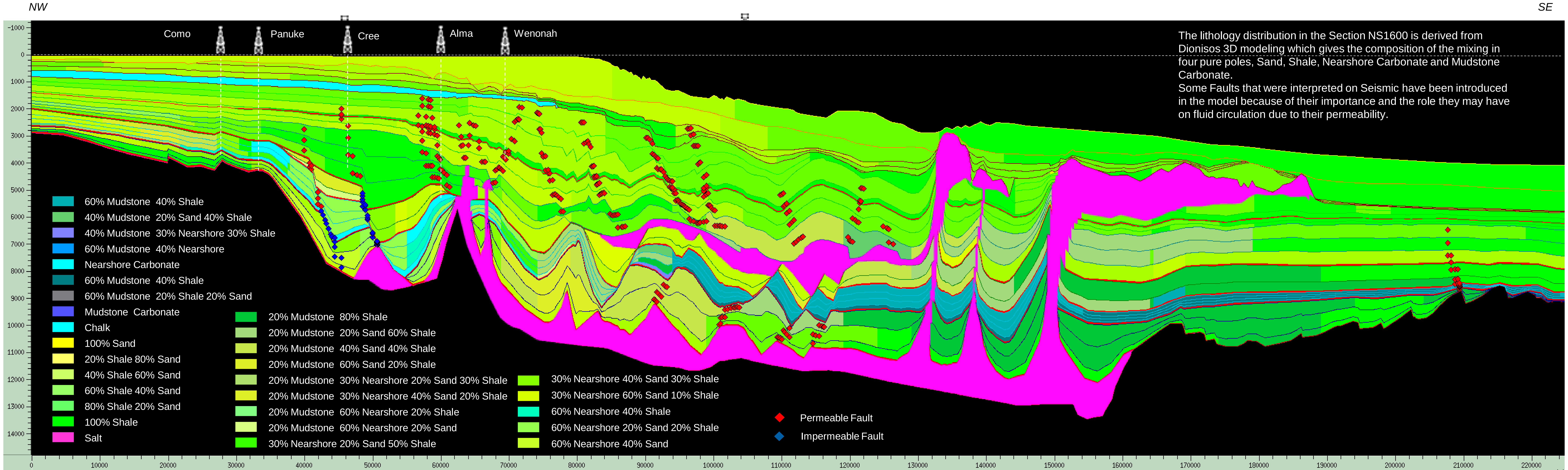


Figure 1: Lithology and Fault zones of Section NS1600 at Present day

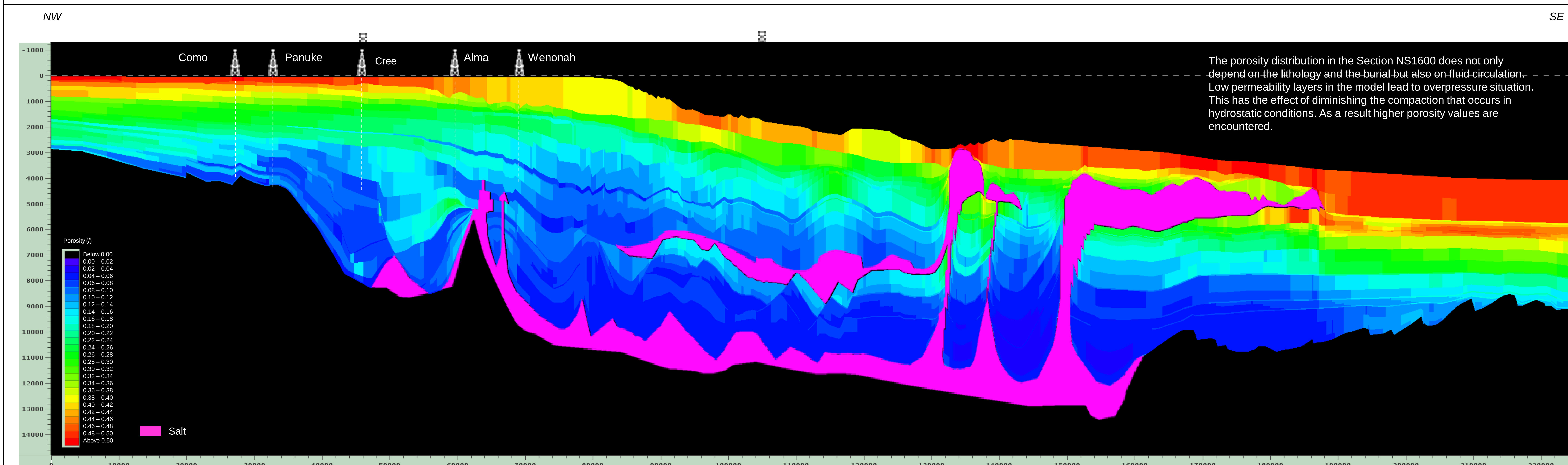


Figure 2: Porosity of Section NS1600 at Present day

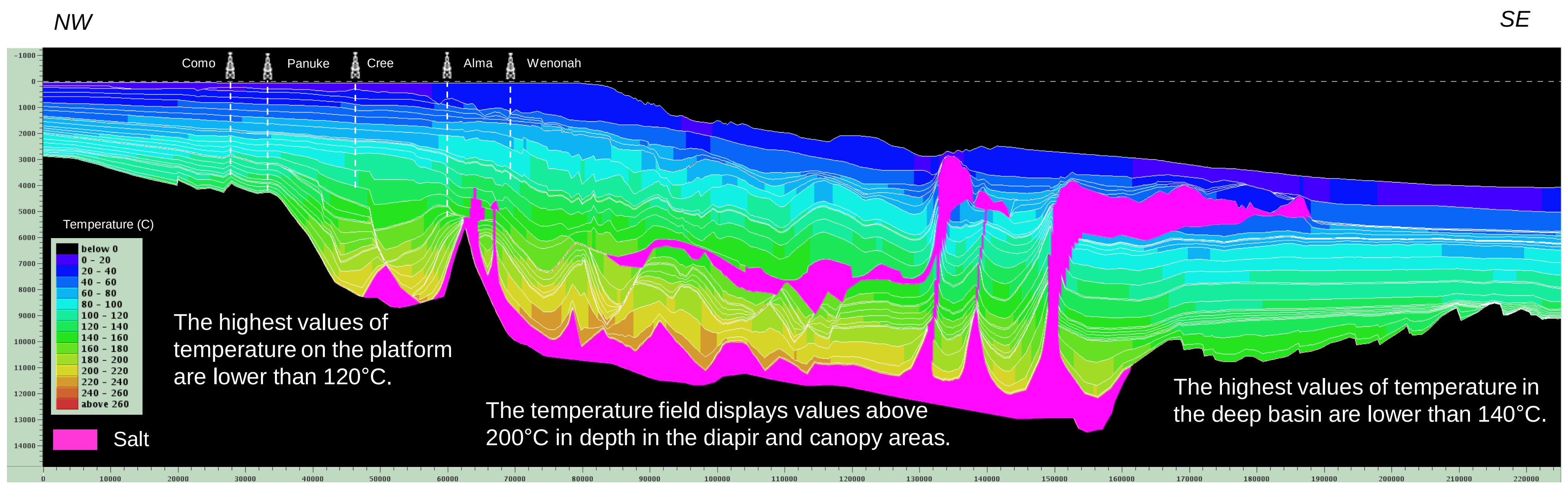
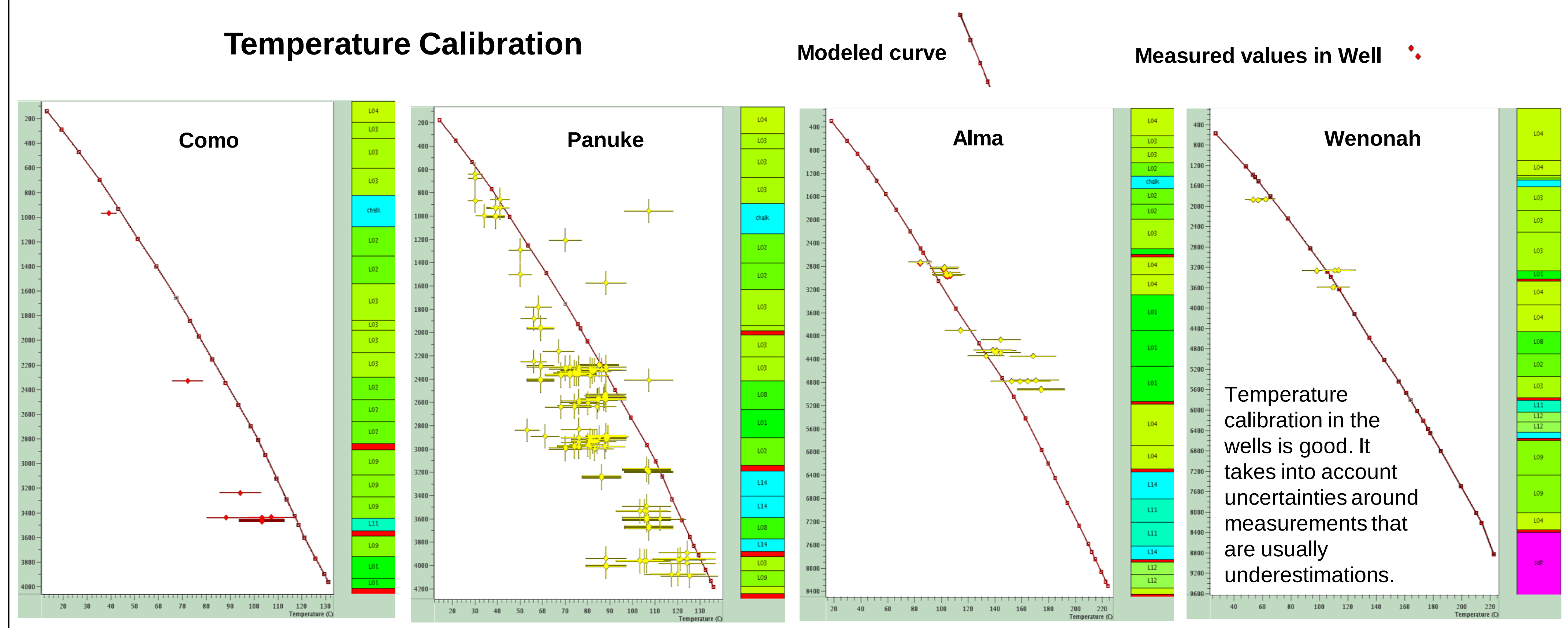


Figure 1: Temperature Field



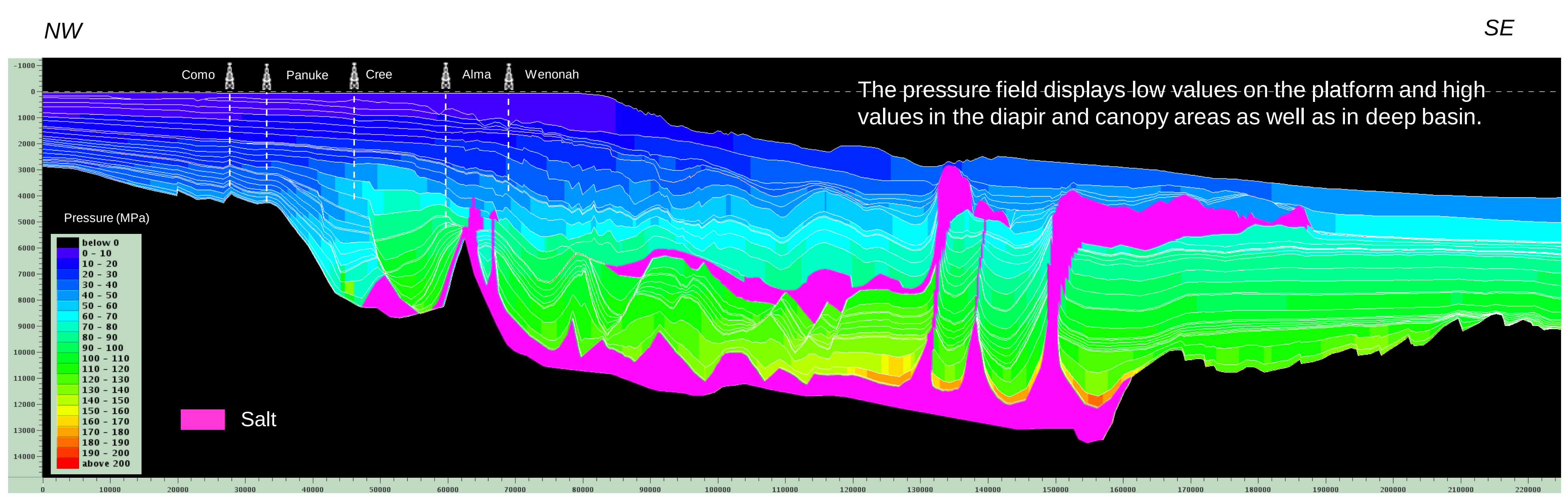
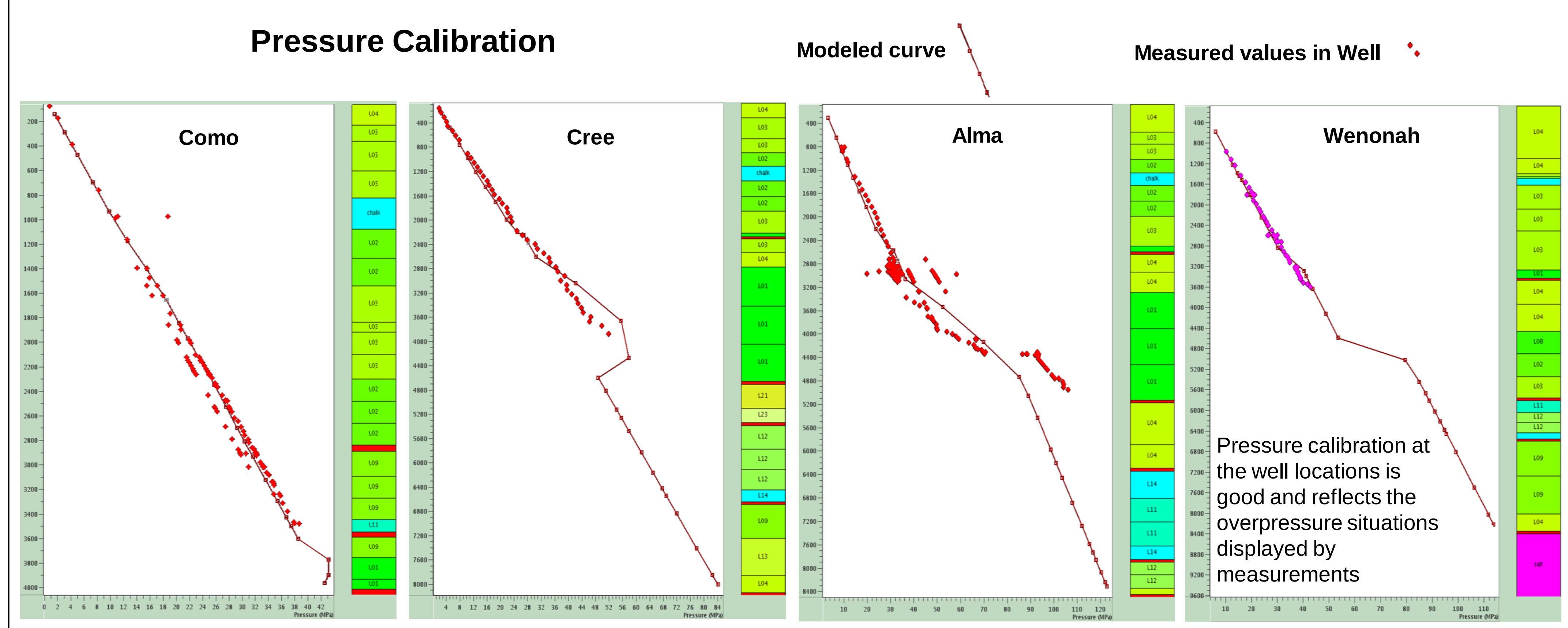


Figure 2: Pressure Field



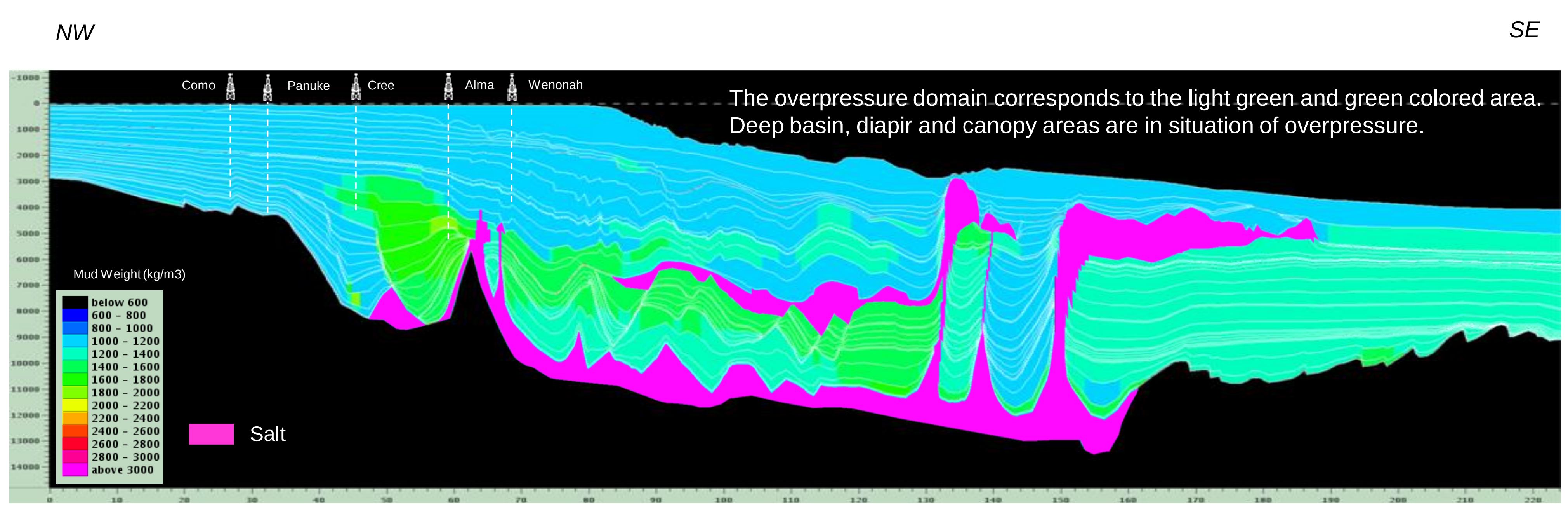
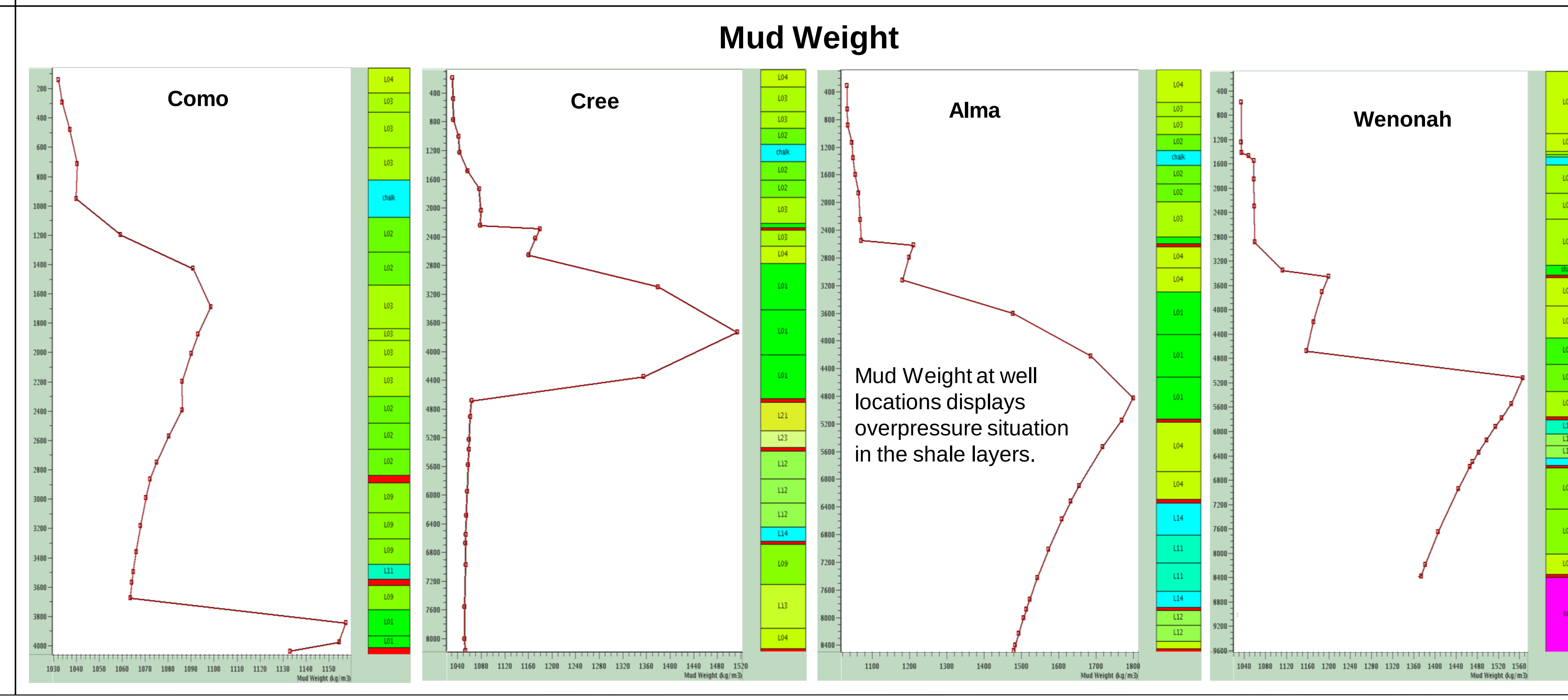


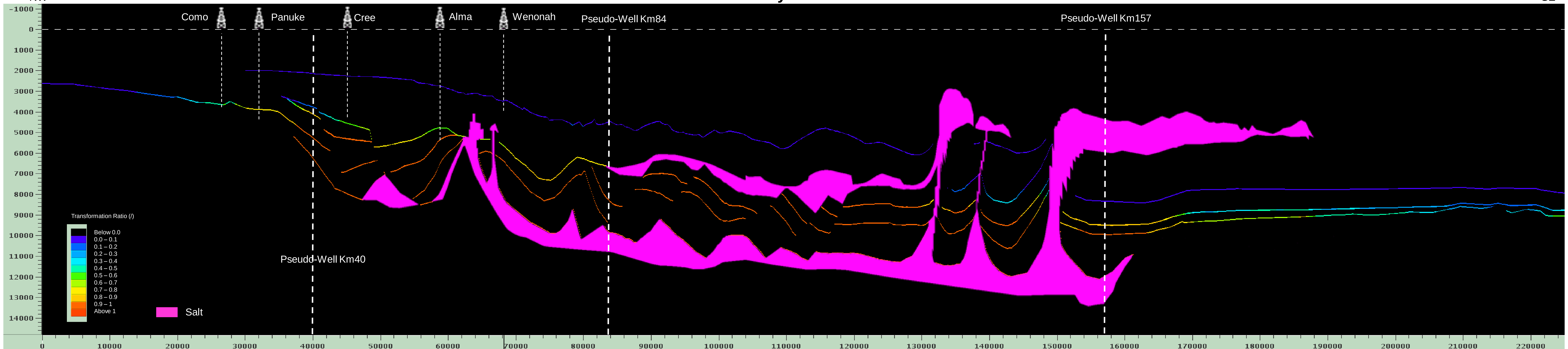
Figure 3: Mud Weight Field



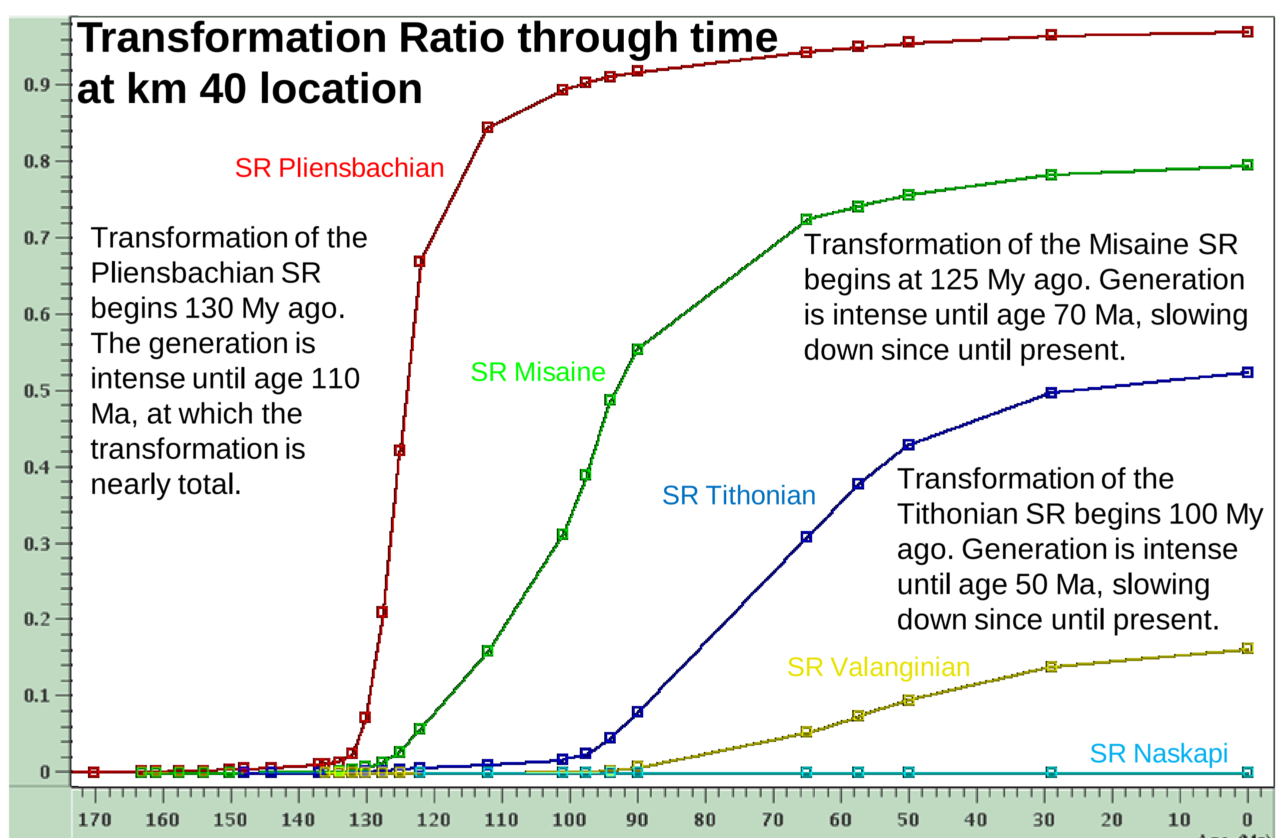
BASIN MODELING – TEMIS 2D

PLAY FAIRWAY ANALYSIS - OFFSHORE NOVA SCOTIA - CANADA – June 2011

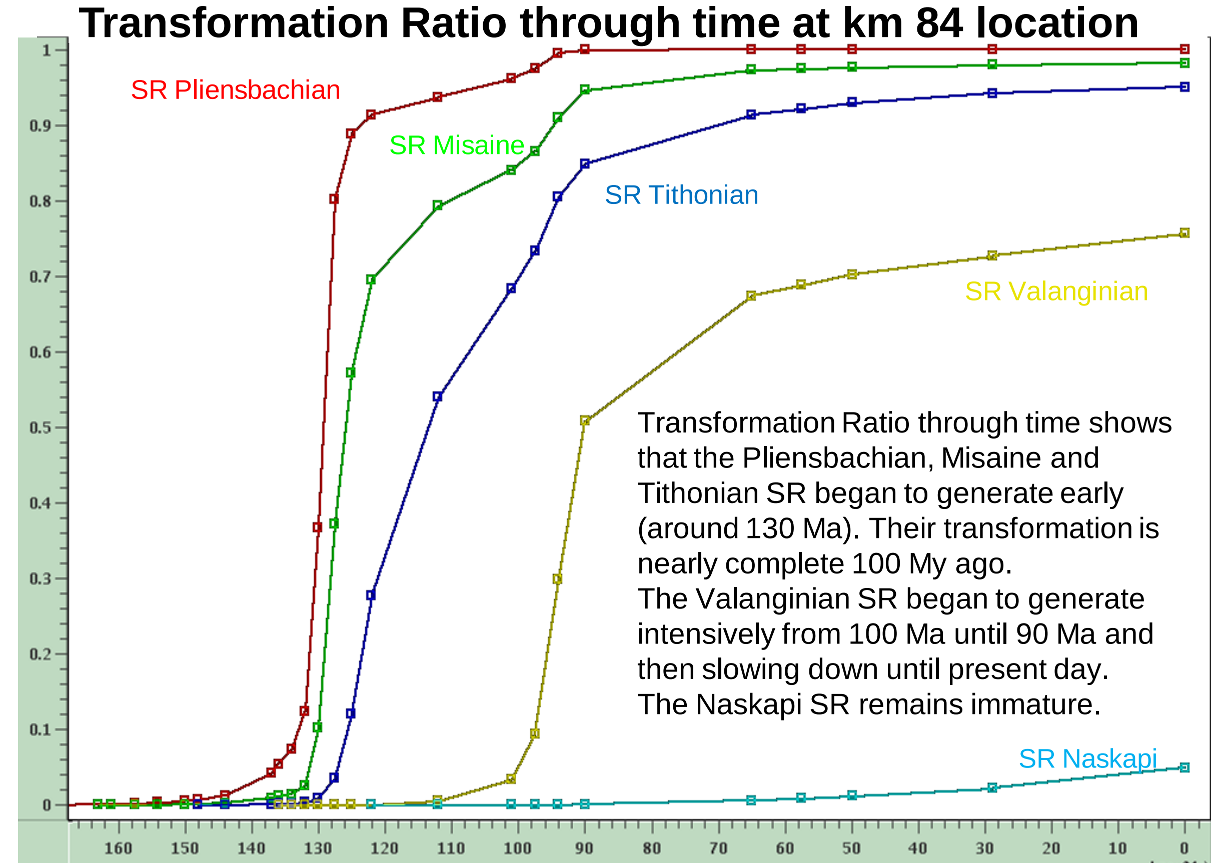
Transformation Ratio at Present Day for the Source Rocks of Section NS1600



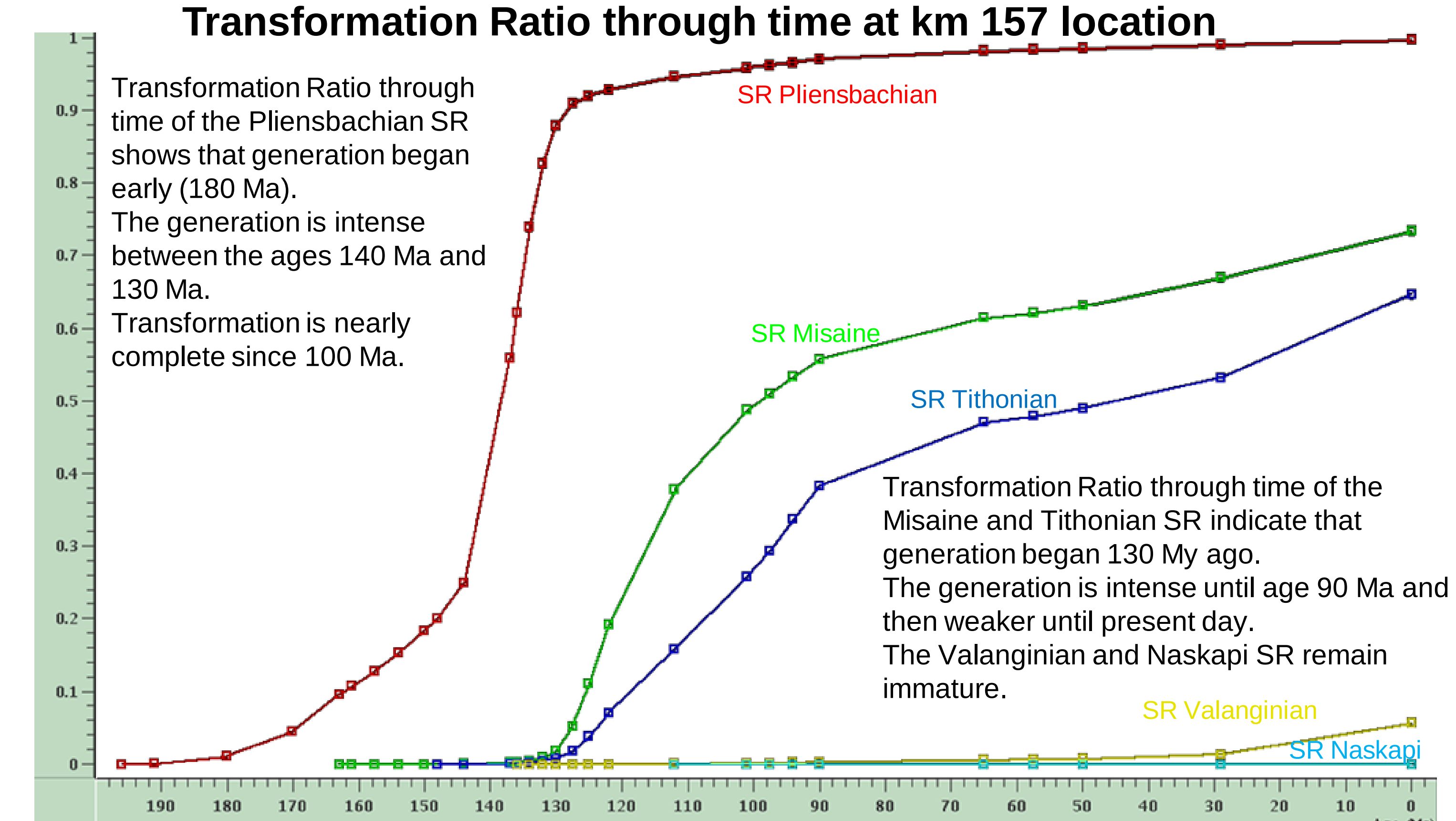
Transformation Ratio through time at km 40 location



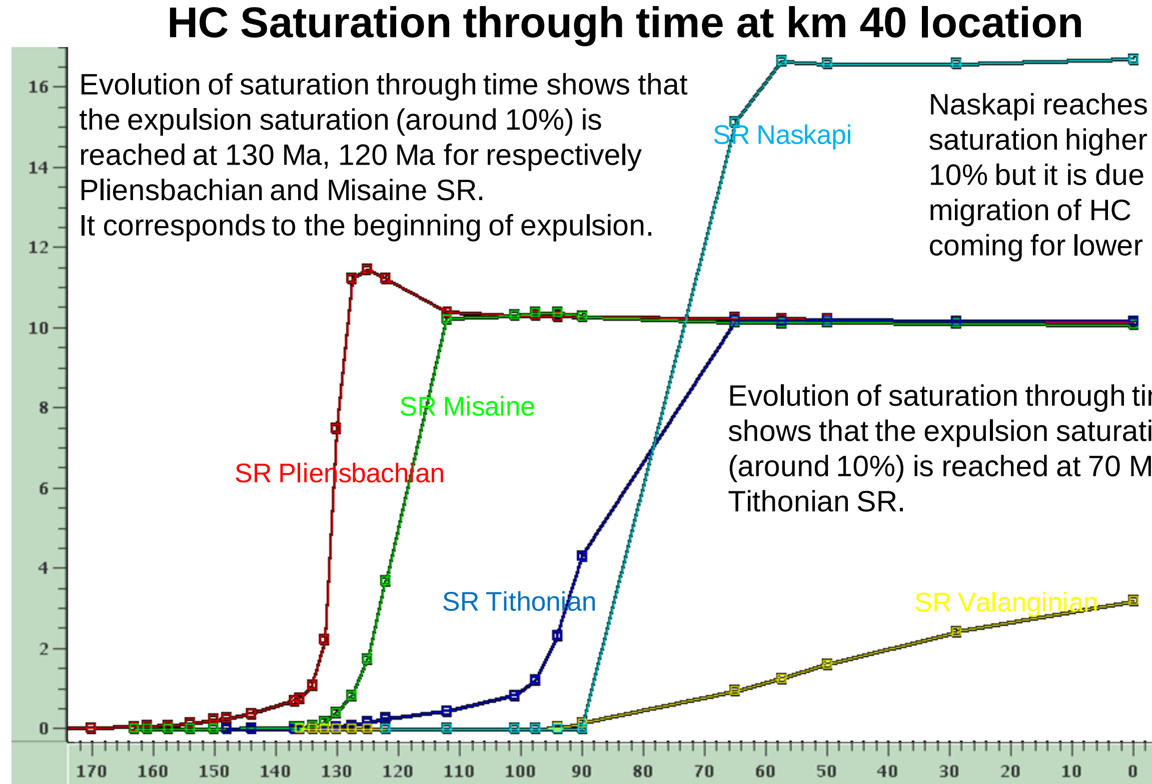
Transformation Ratio through time at km 84 location



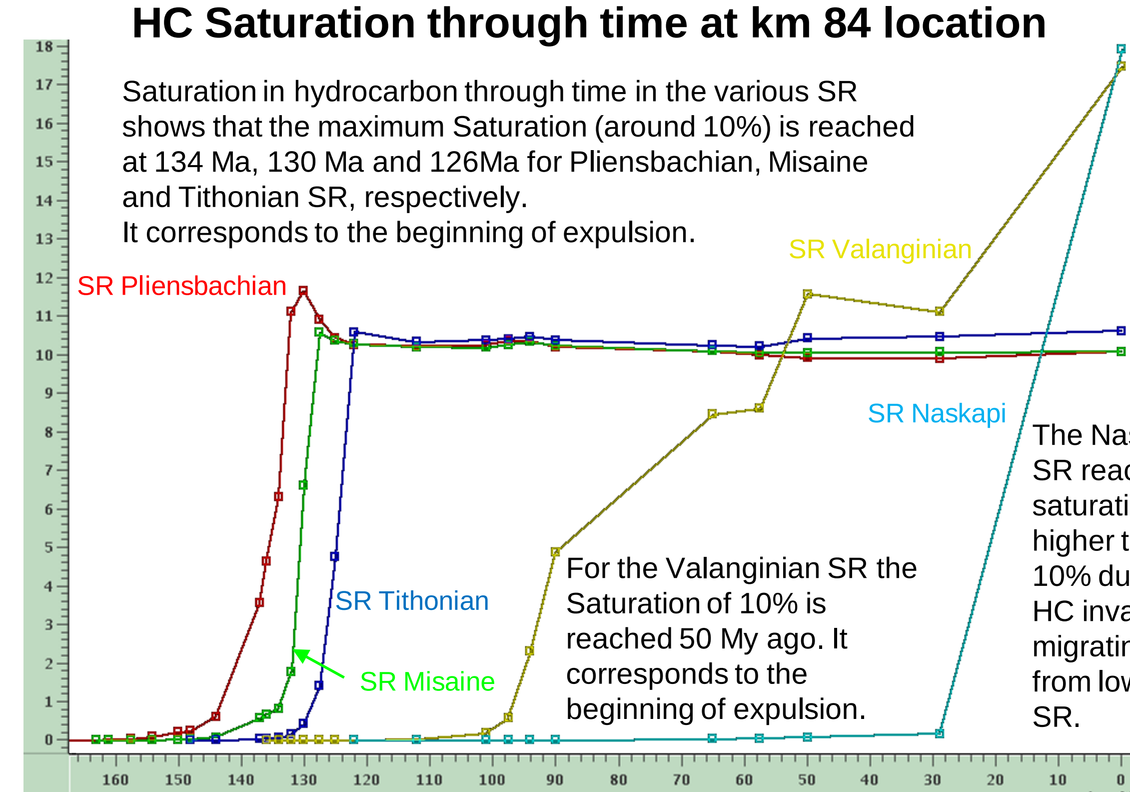
Transformation Ratio through time at km 157 location



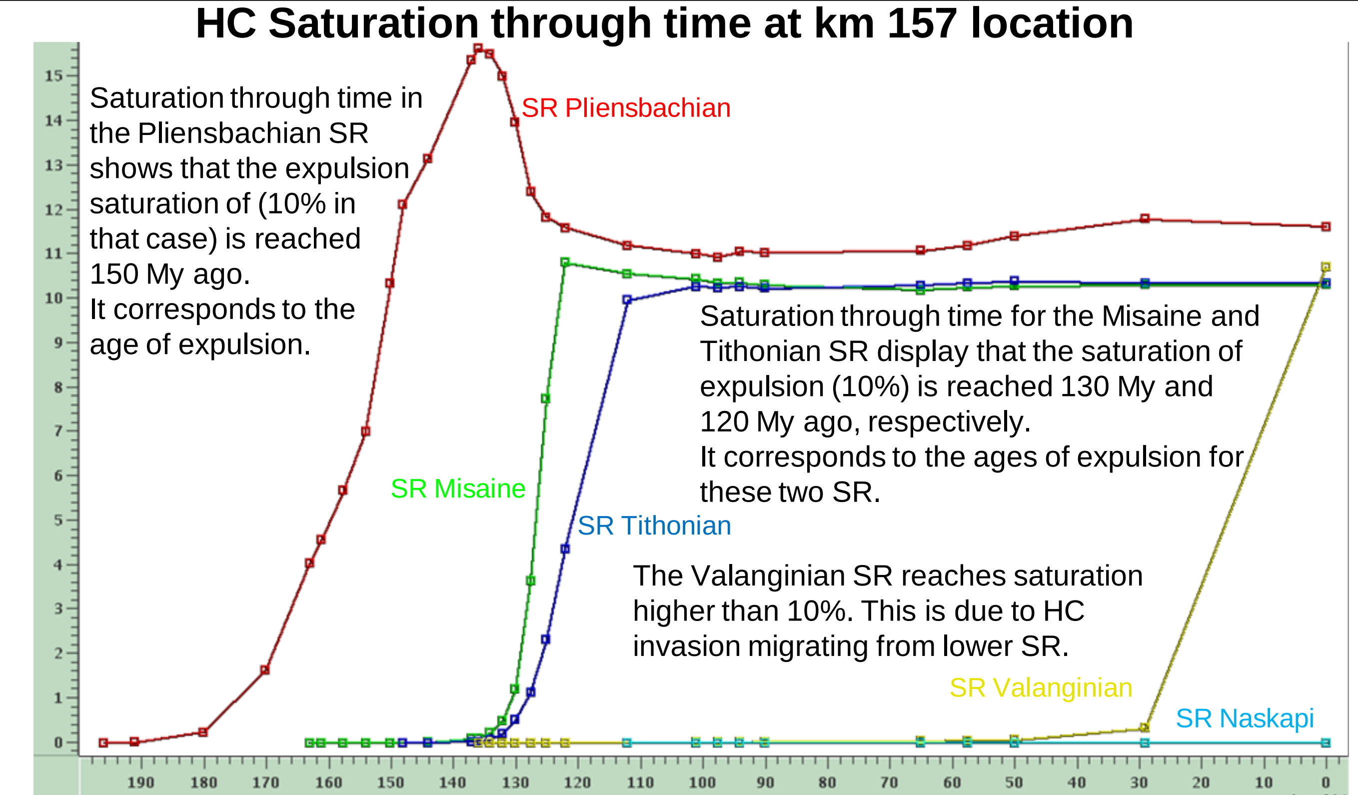
HC Saturation through time at km 40 location



HC Saturation through time at km 84 location



HC Saturation through time at km 157 location



Transformation Ratio and Expulsion through Time at 3 Pseudo Well locations - Section NS1600 PL. 7-2-4-3b

BASIN MODELING – TEMIS 2D

In the salt area, hydrocarbons are expelled from the Pliensbachian Source Rock and invade the Early Jurassic layers.

NW SE

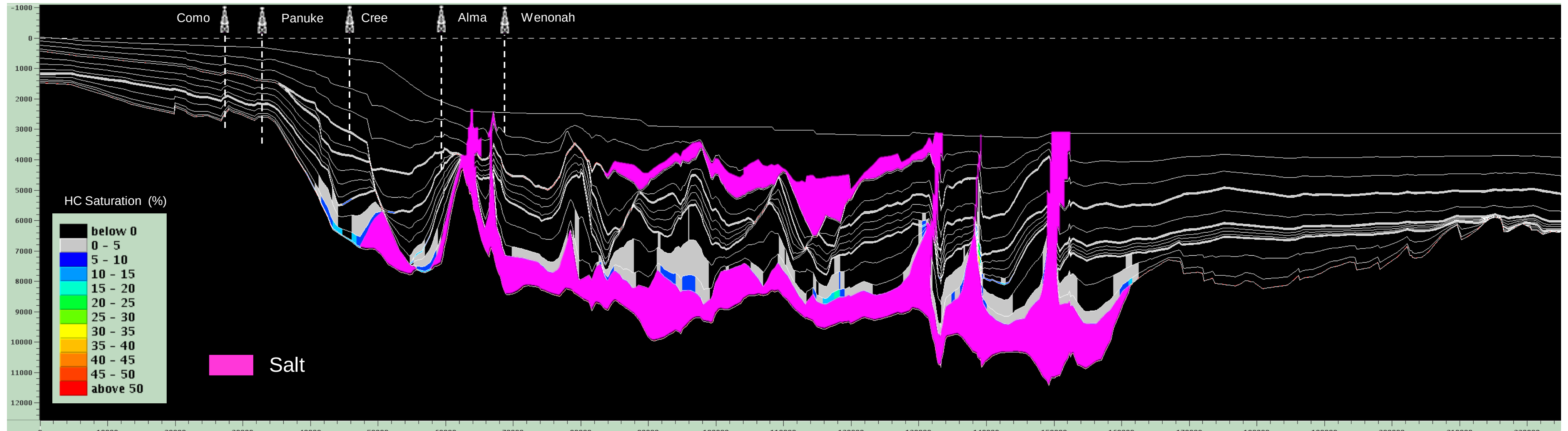


Figure 1: Hauterivian- 130 Ma

In the salt area, expulsion from the Pliensbachian Source Rock goes on. Hydrocarbons migrate upward to the Early Jurassic layers and in some cases up to Late Jurassic layers.

NW SE

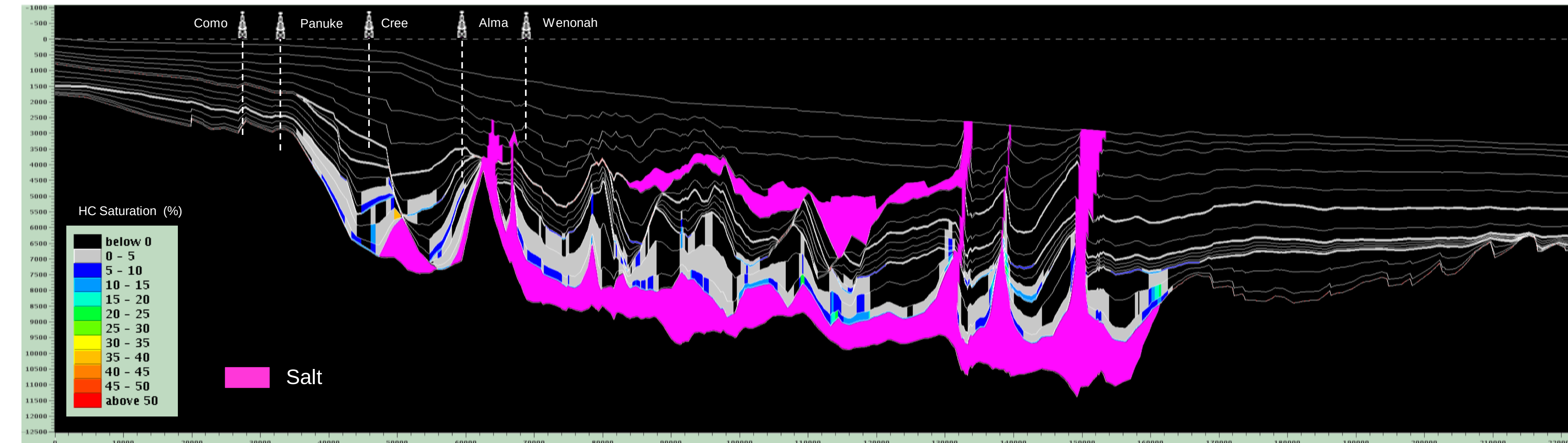


Figure 2: Barremian - 125 Ma

Expulsion from the Pliensbachian source rock progresses. The Misaine and Tithonian source rocks also expel in Aptian time. Migrant hydrocarbons reach upward the Jurassic and the Early Cretaceous layers.
Hydrocarbons migrate laterally within the Early Jurassic layers toward the Jurassic carbonate platform edge.

NW SE

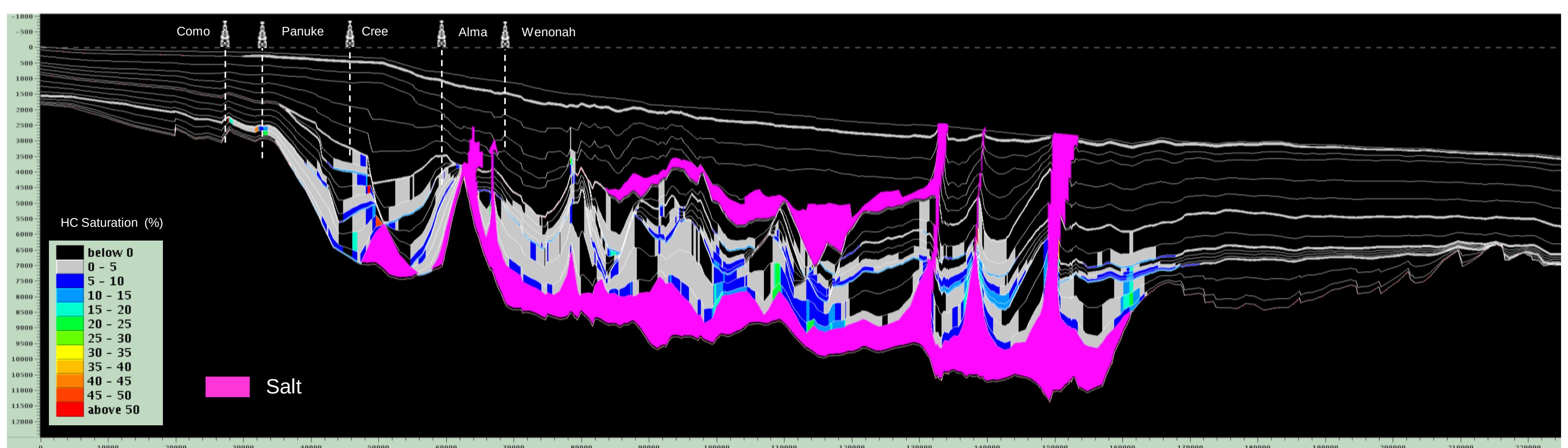


Figure 3: Aptian - 112 Ma

Hydrocarbon expulsion from the Pliensbachian, Misaine and Tithonian source rocks is progressing.
Hydrocarbons expelled from the Pliensbachian SR located in the salt area migrate laterally within the Early Jurassic layers up to the carbonate platform edge. There, they accumulate in anticline structures in the Panuke and Como areas.

NW SE

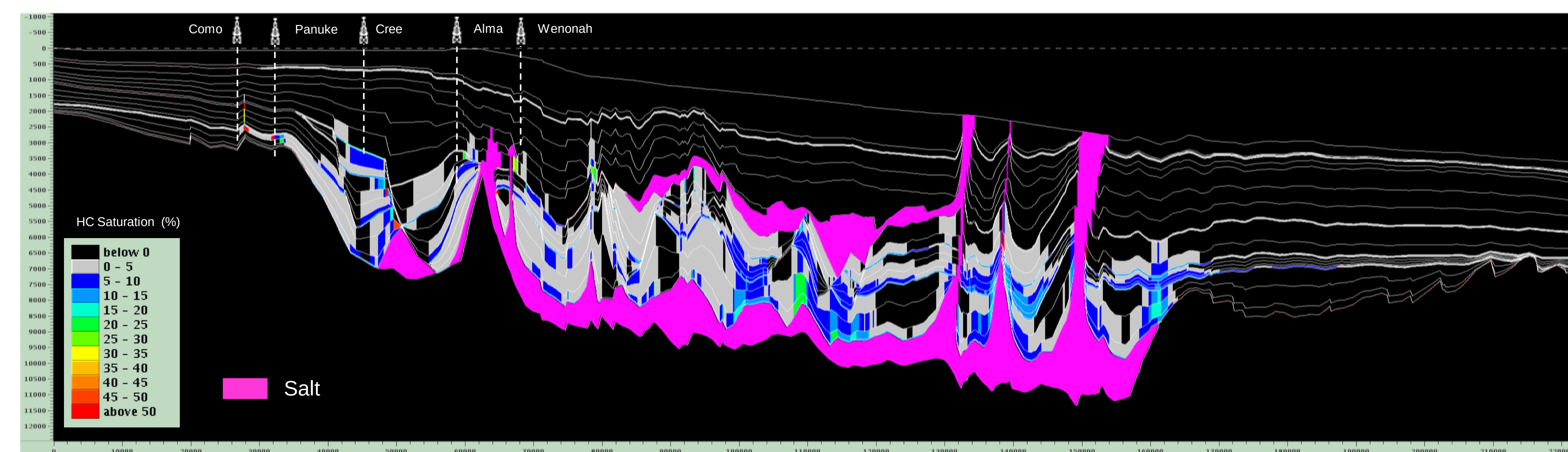


Figure 4: Albian - 101 Ma

The expulsion continues from Pliensbachian, Misaine and Tithonian Source Rocks.
Migration of HC is very much in progress upward.
On the platform, at Como location HC are migrating vertically upward reaching Aptian Layer.
Another way of migration in direction to the platform exists, HC generated in Misaine and Thitonian SR tends to migrate laterally in the Valanginian Layers.

NW SE

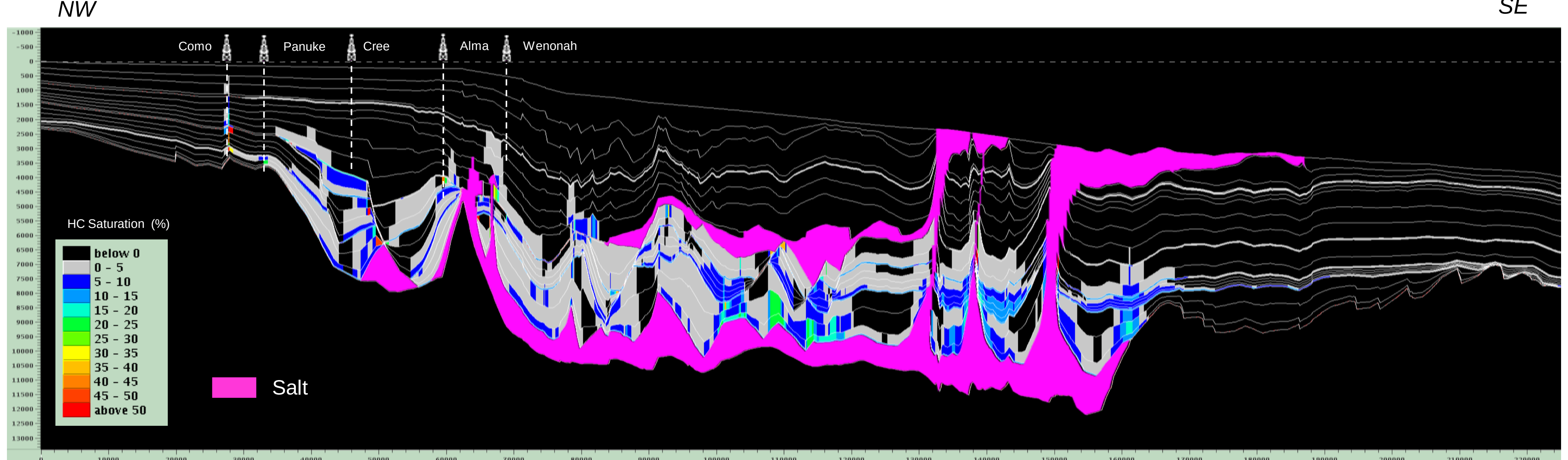


Figure 5: Cenomanian – 94 Ma

At Como location HC are progressing vertically upward to the topography.

Another accumulation is forming in the platform at Panuke location in the Valanginian Layers.

In the transition area between the platform and the slope, vertical migration also reaches Valanginian-Hauterivian layers, at Alma, Wenonah and at kilometer 80 of the Section.

NW SE

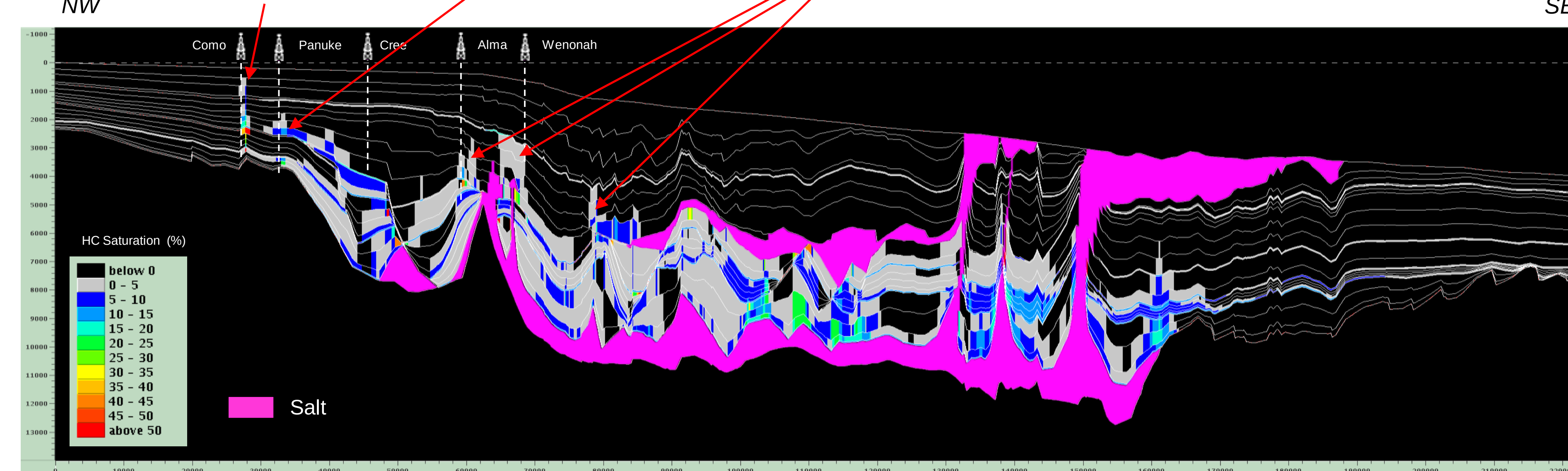


Figure 6: Turonian- 90 Ma

HC Saturation through time - Section NS 1600

BASIN MODELING – TEMIS 2D

At Como and Panuke migration and accumulation are in progress.

The model suggests that hydrocarbons migrate laterally in the direction of the platform from the Alma location toward the Panuke area.

Large accumulations are forming under the salt canopies. Note that 2D modeling forces hydrocarbons generated in the section to stay in the section except for leaks at section ends. Similarly accumulations cannot leak sideways off section

NW SE

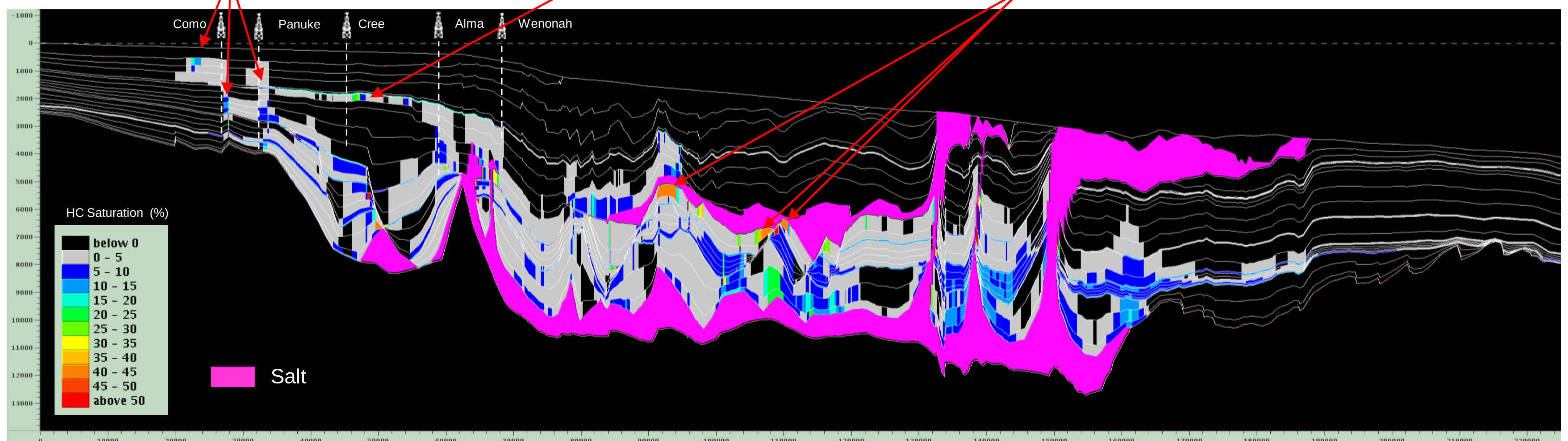


Figure 1: Maastrichtian - 65 Ma

At Como and Panuke migration and accumulation continue to progress.

Hydrocarbons lateral migration in the direction of the platform from the Alma location sealed by the Naskapi shale goes on

Large accumulations are forming under the salt canopies. Note that 2D modeling forces hydrocarbons generated in the section to stay in the section except for leaks at section ends. Similarly accumulations cannot leak sideways

NW SE

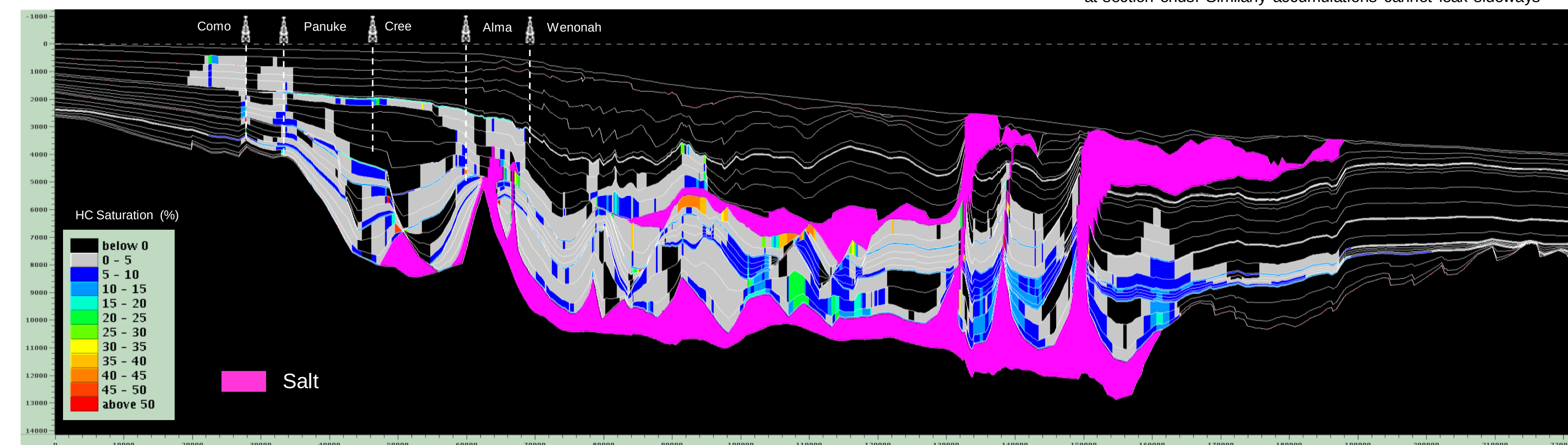


Figure 2: Thanetian – 57.5 Ma

Accumulation close to topography on platform.

Accumulation under Naskapi layer in the slope.

Great accumulations under salt canopies in the slope area.

NW SE

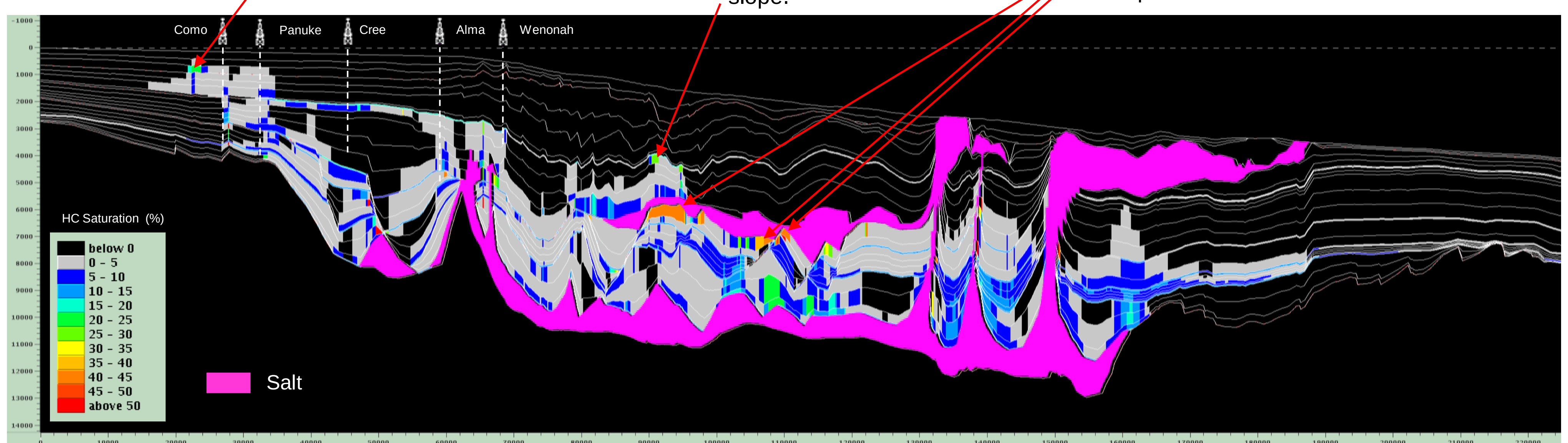


Figure 3: Ypresian - 50 Ma

Shallow accumulations form on the platform.

Hydrocarbon charge in reservoirs sealed by the Naskapi layer improves.

Hydrocarbon charge in reservoirs sealed by salt canopies also improves.

NW SE

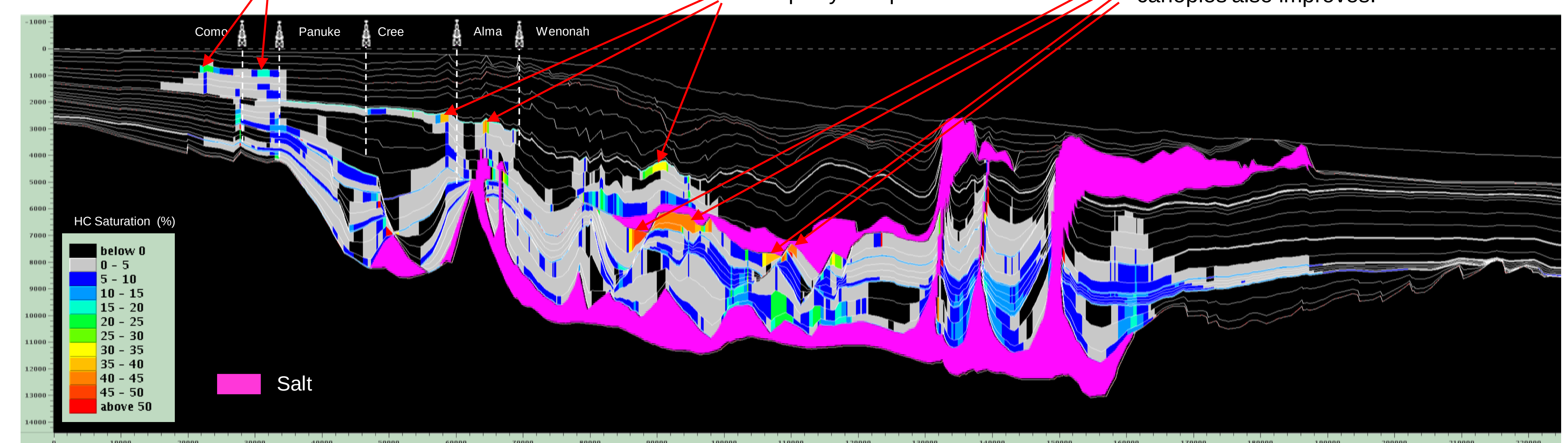


Figure 4: Rupelian - 29 Ma

NW SE

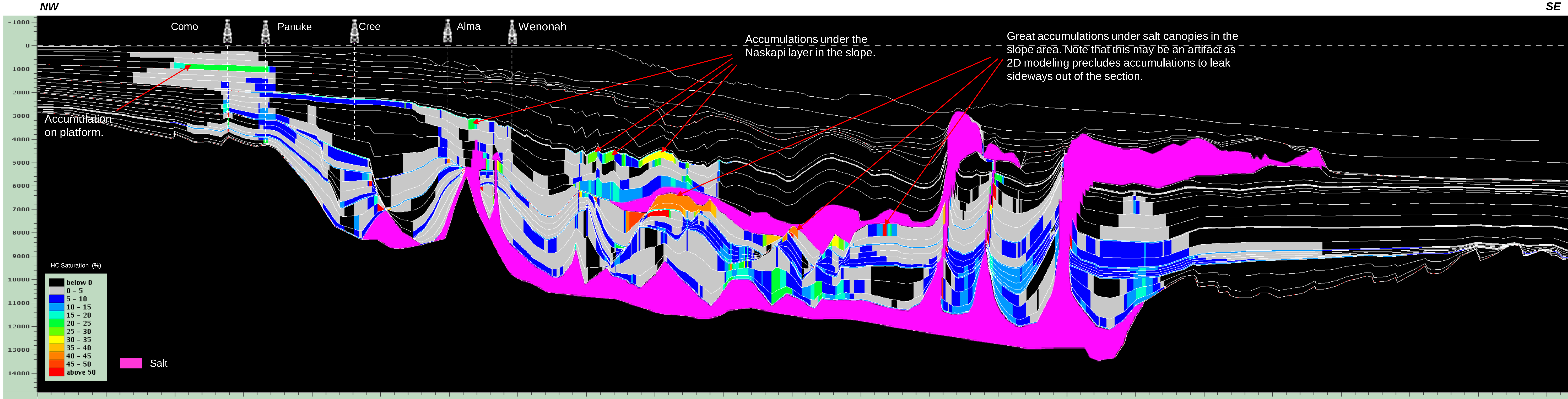


Figure 5: Present day – 0 Ma

The maturity field at present day defines the oil and gas windows, and the over mature zone in the section. In the salt domain, the gas window and the over mature zone are extensive. Above, the oil window affecting the whole section includes the Jurassic carbonate platform edge.

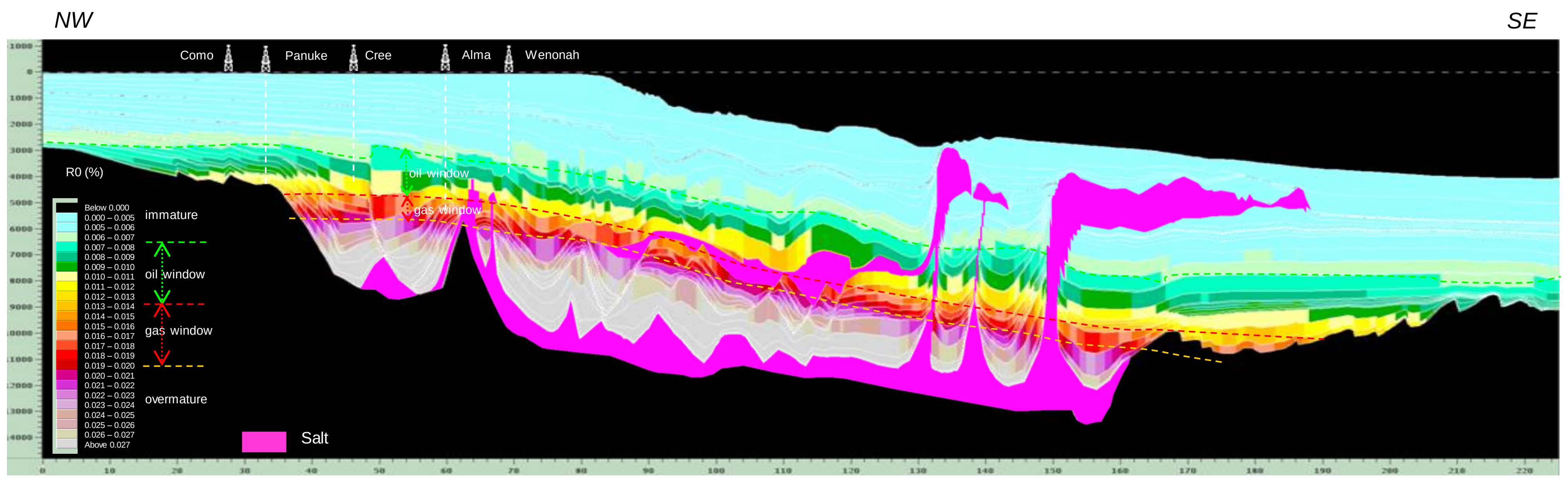


Figure 1: R0 Maturity

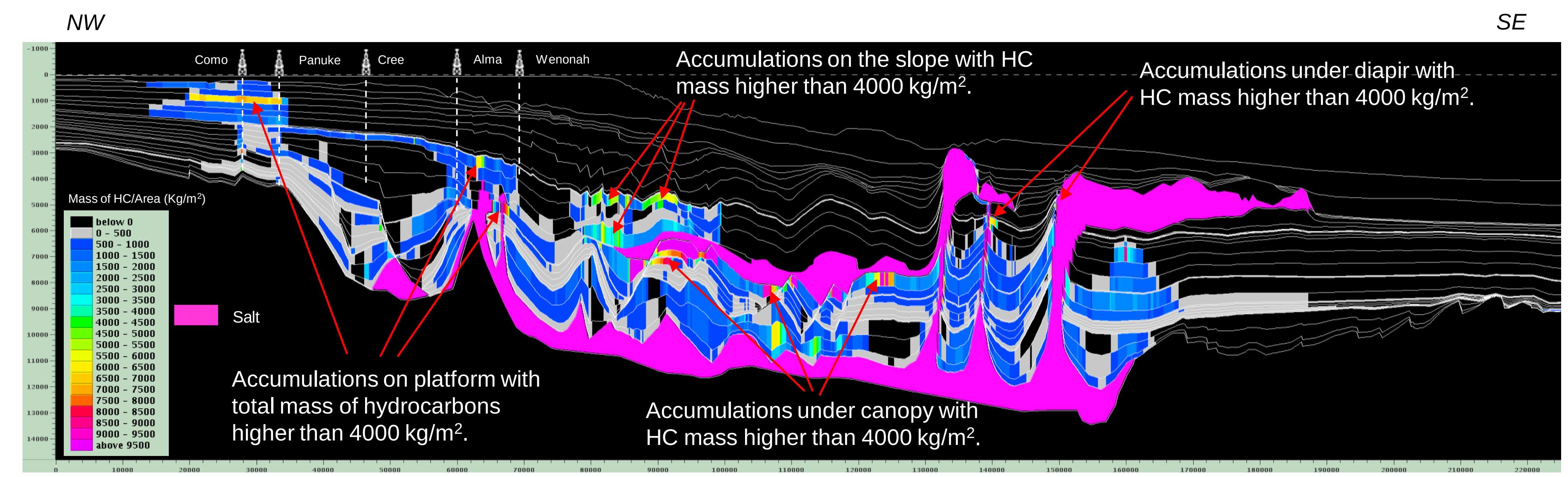


Figure 2: Total HC Mass

The mass fraction of gas higher than 500 kg/m² corresponds to the blue colored area, it corresponds also to the area where hydrocarbons are present in the section (See fig 2). Gas is therefore the dominant hydrocarbon fraction in the section.

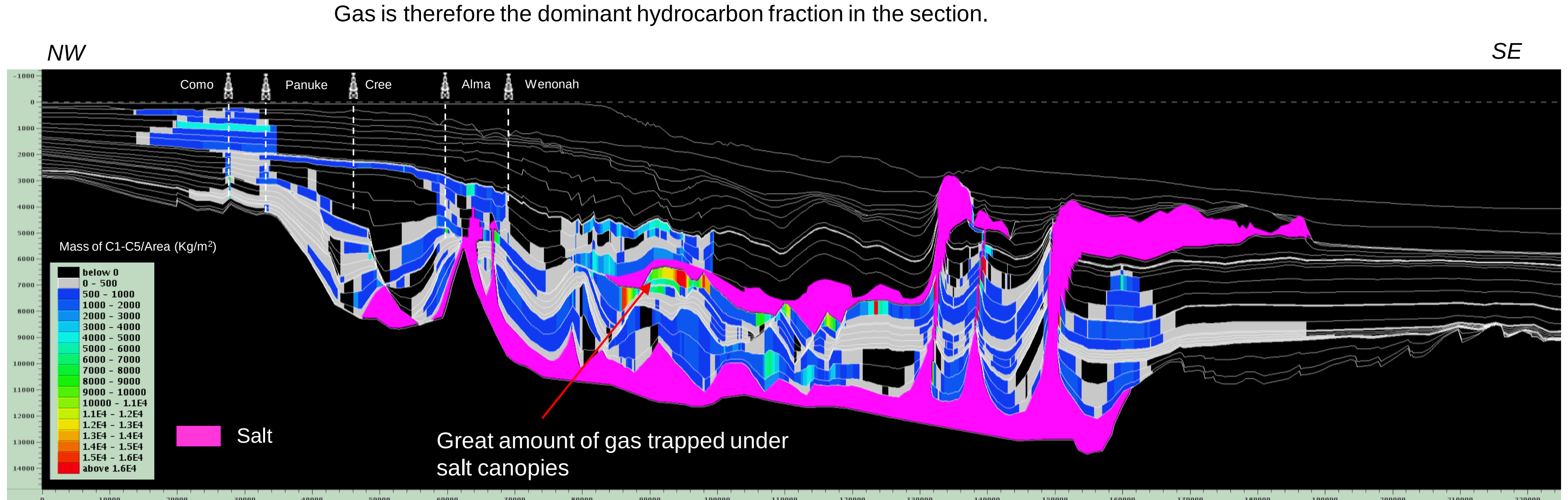


Figure 3: Fraction C1-C5

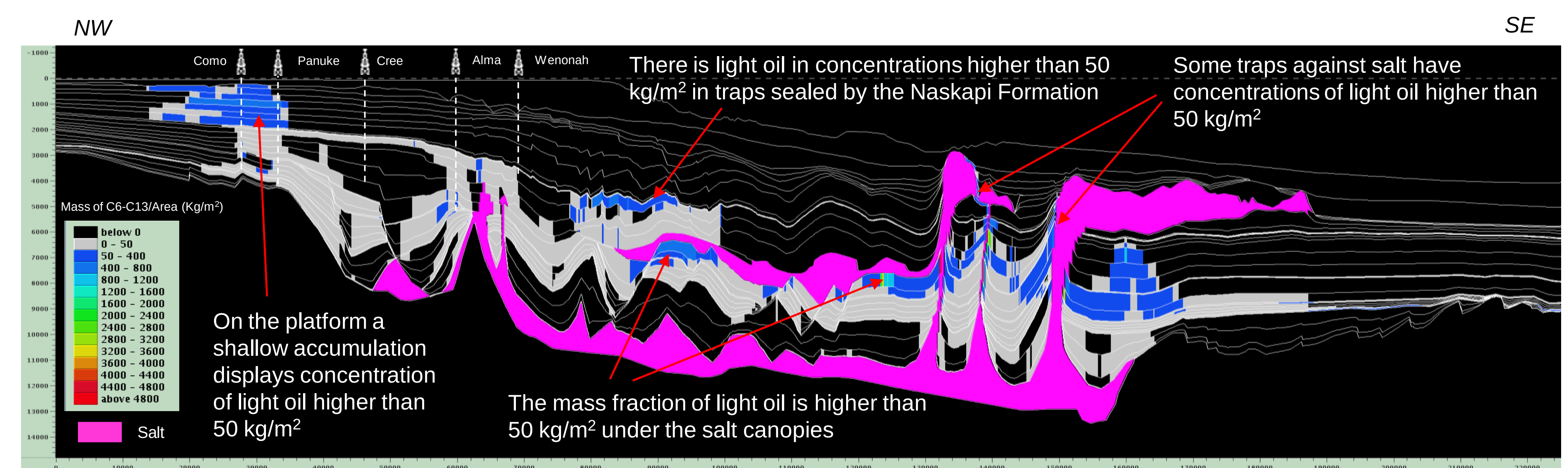


Figure 4: Fraction C6-C13

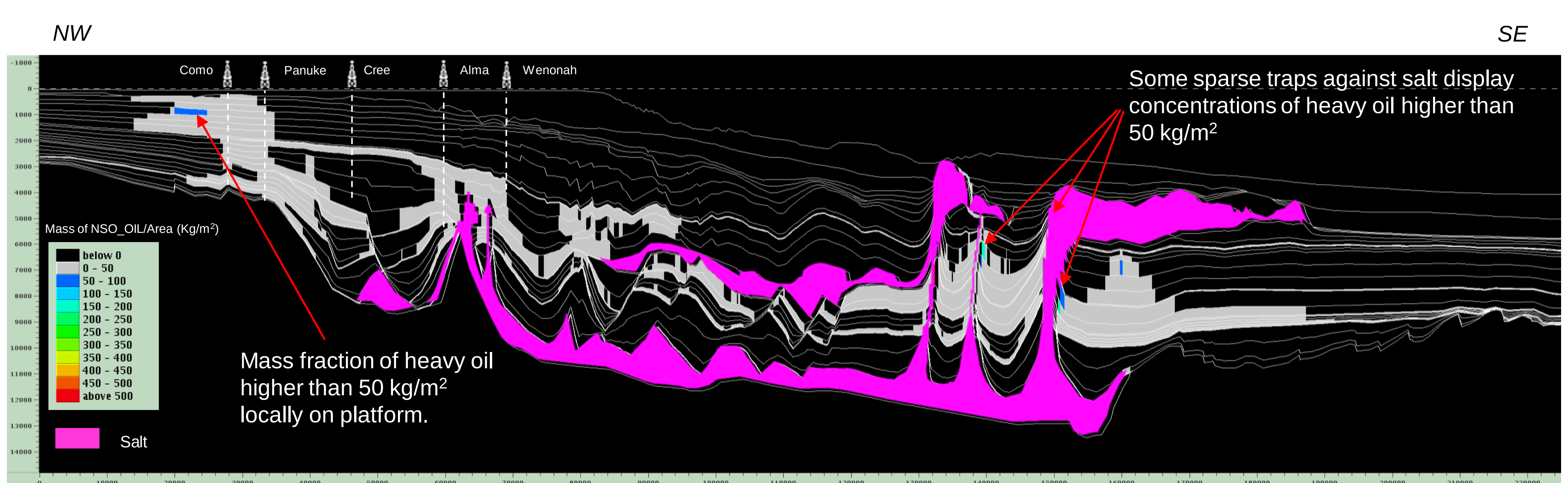


Figure 5: Fraction Nitrogen / Sulfur / Oxygen OIL

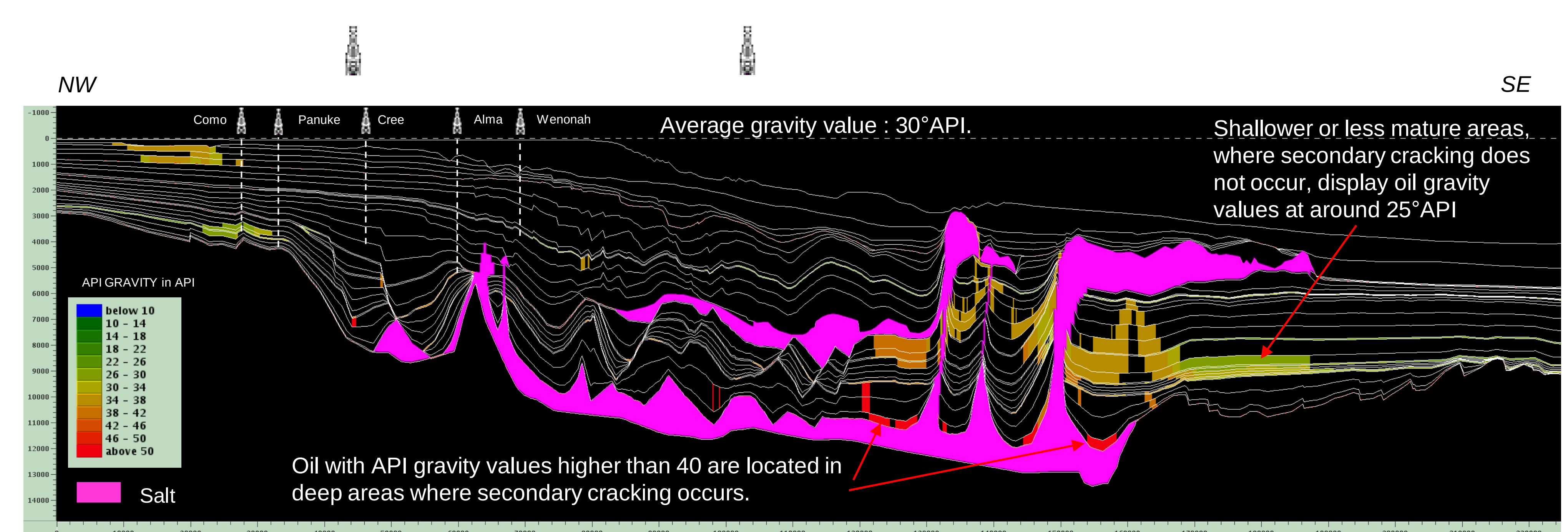
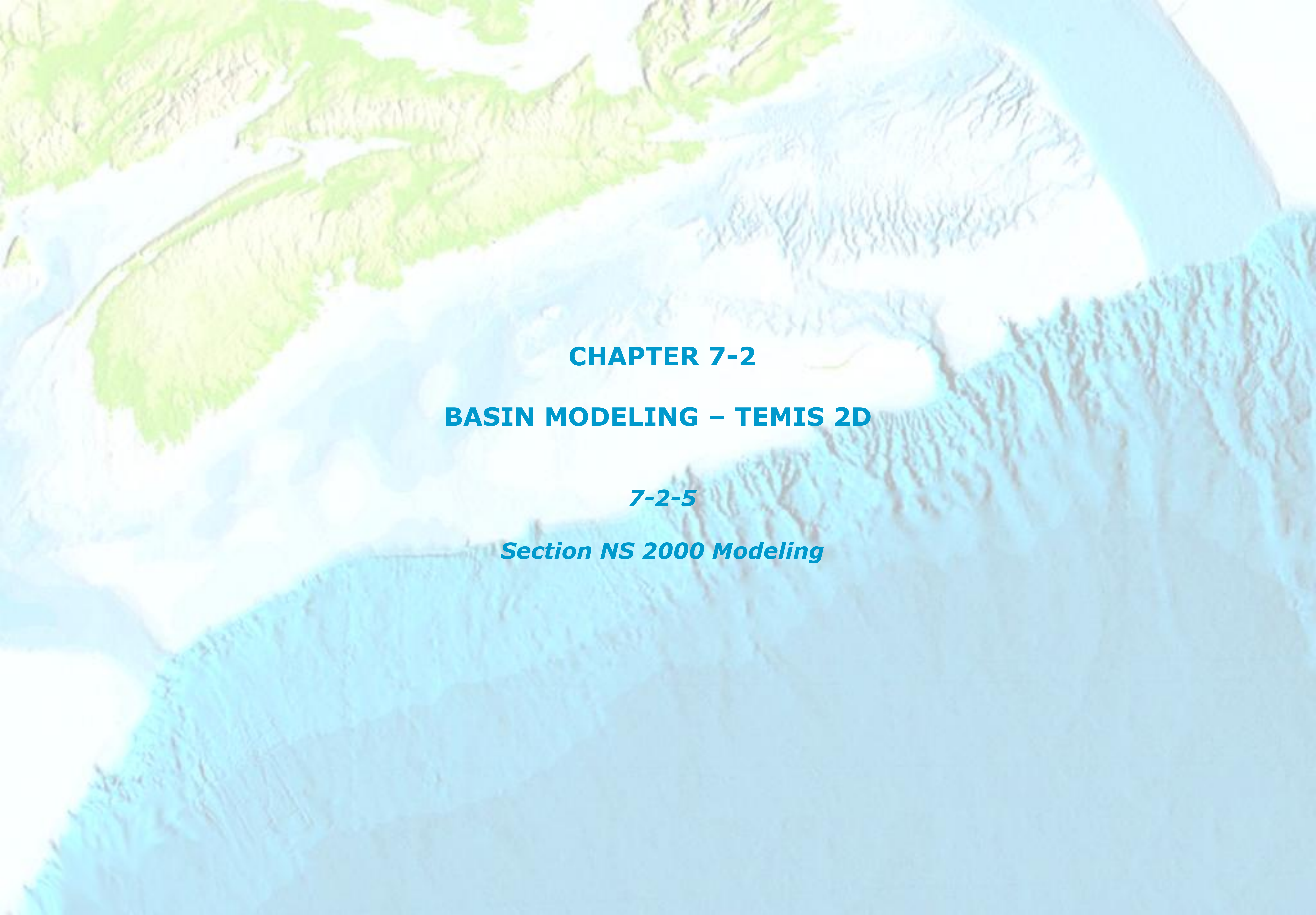


Figure 6: API Gravity

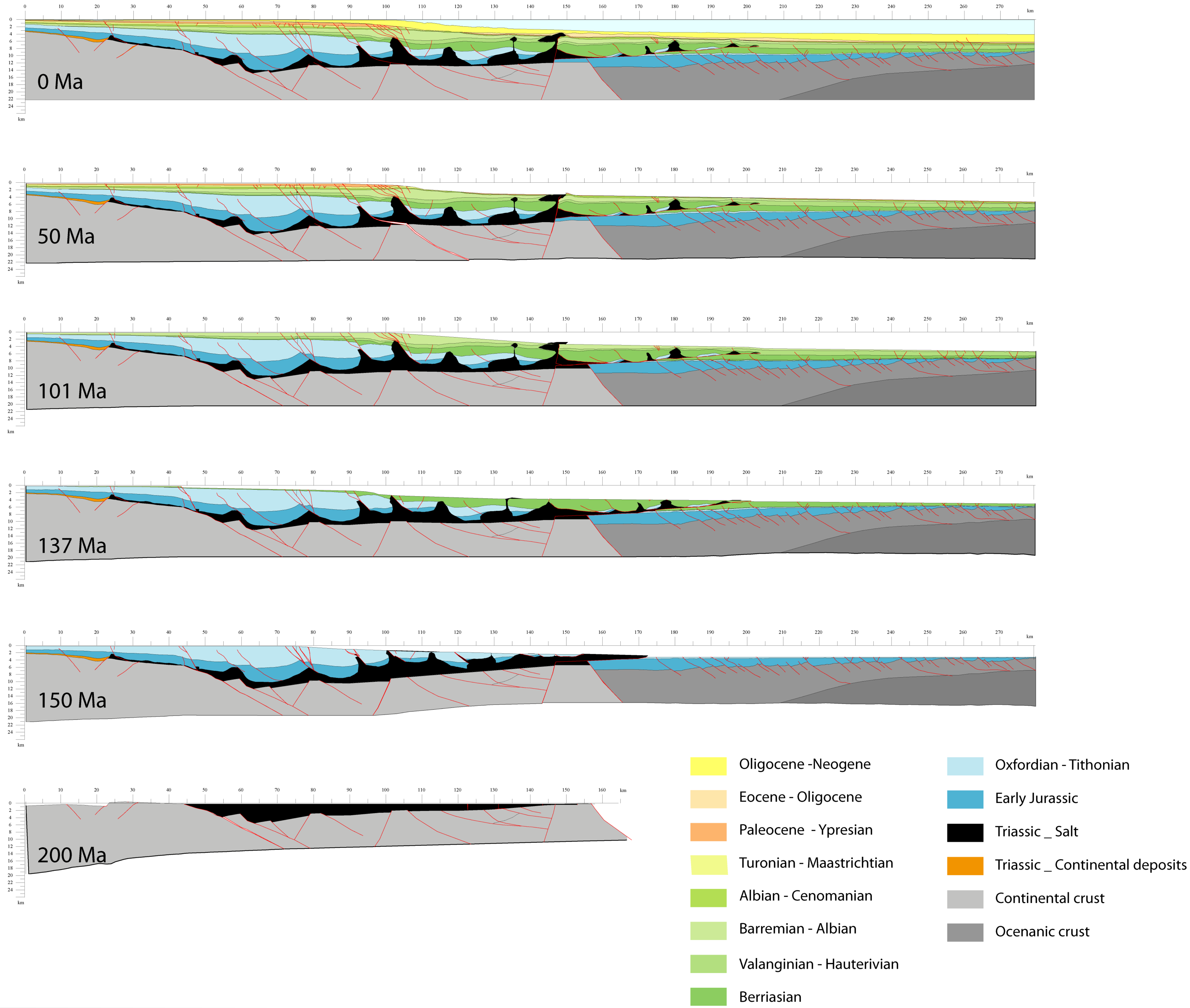


CHAPTER 7-2

BASIN MODELING – TEMIS 2D

7-2-5

Section NS 2000 Modeling



Restoration of Section NS2000

BASIN MODELING – TEMIS 2D

PLAY FAIRWAY ANALYSIS - OFFSHORE NOVA SCOTIA - CANADA – June 2011

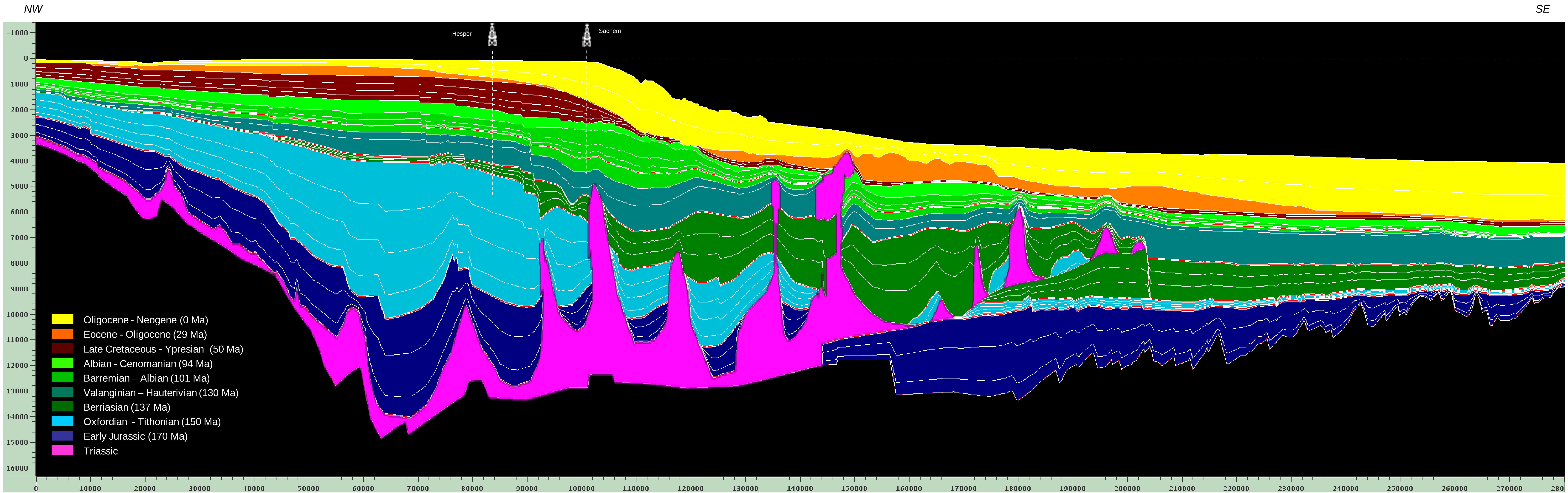


Figure 1: Stratigraphy of the Section NS2000 at Present day

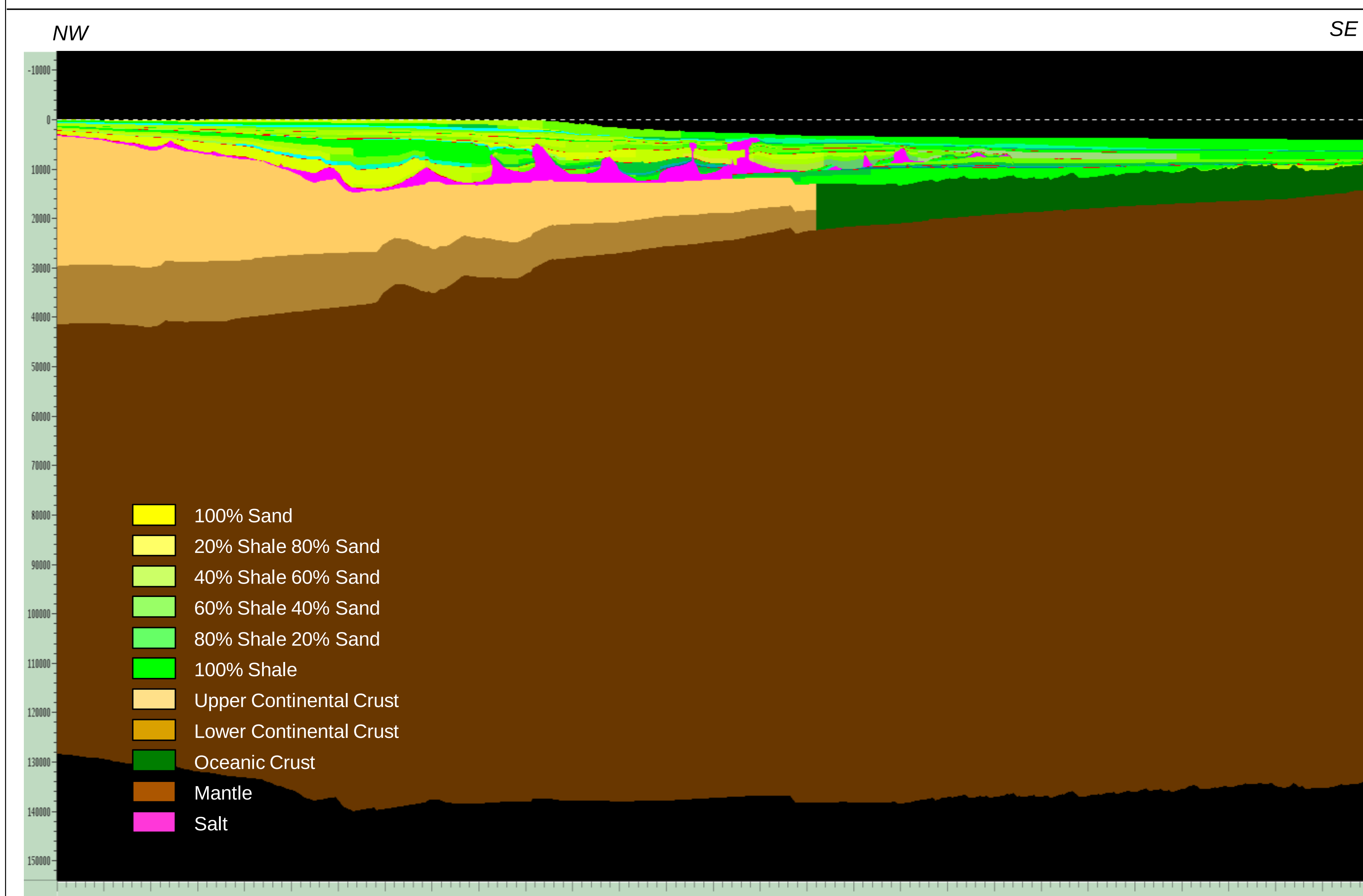


Figure 2: Lithosphere geometry of Section NS2000 at Present day

The limit between continental and oceanic crust domains is at kilometer 165 in the model.
The crust maximum thickness is at the north of the section where the value is close to 40 km. On the contrary the crust thickness is minimum at the south of the section where it is close to 8 km.

The Section NS2000 is 280 kilometers length located in the center of the study domain.
The northern part of the section is on the continental platform and the southern part is oceanic domain.

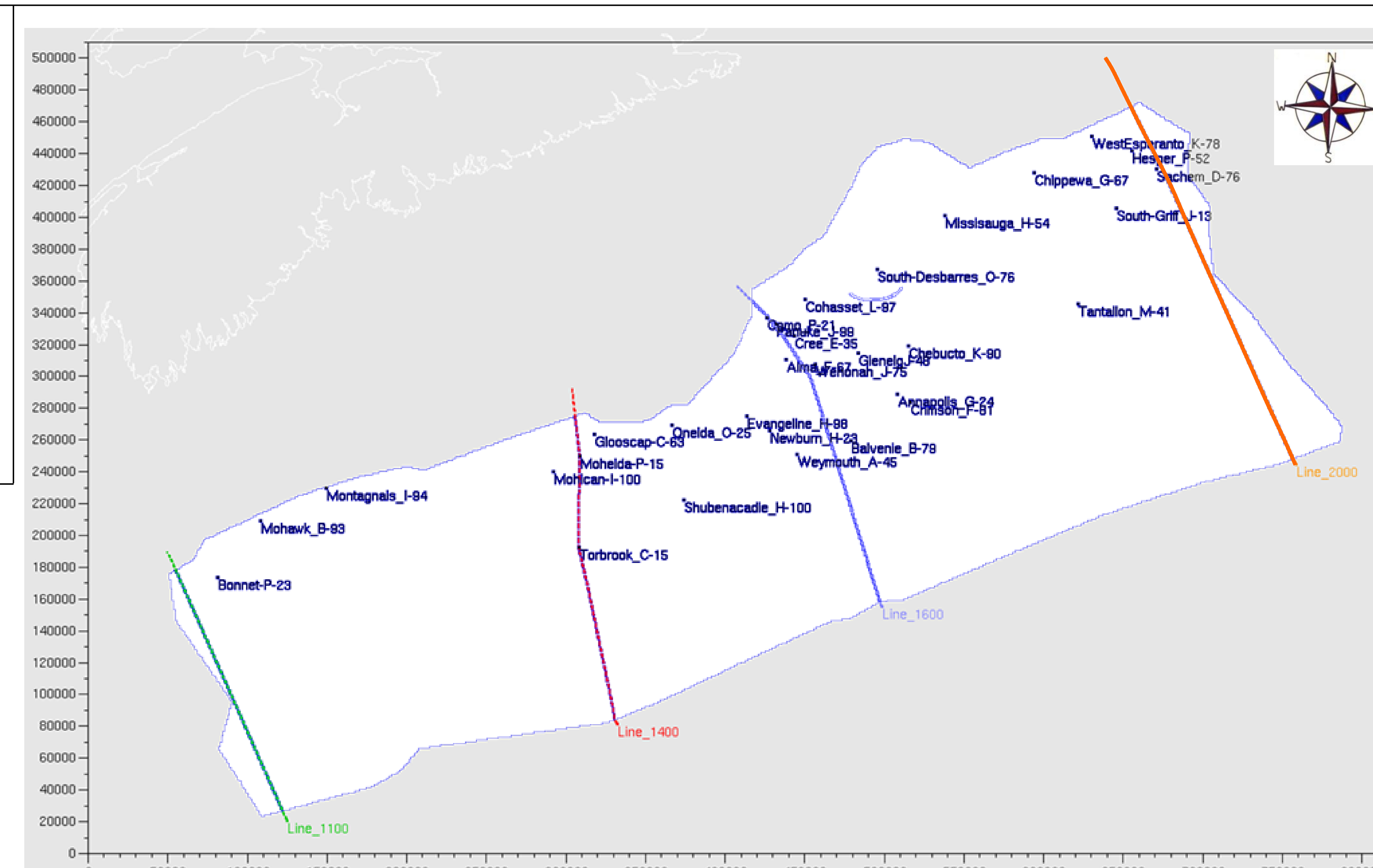


Figure 3: Location of Section NS2000 on Map

PL. 7-2-5-2a **Stratigraphy, Basement geometry and Location Map of Section NS2000**

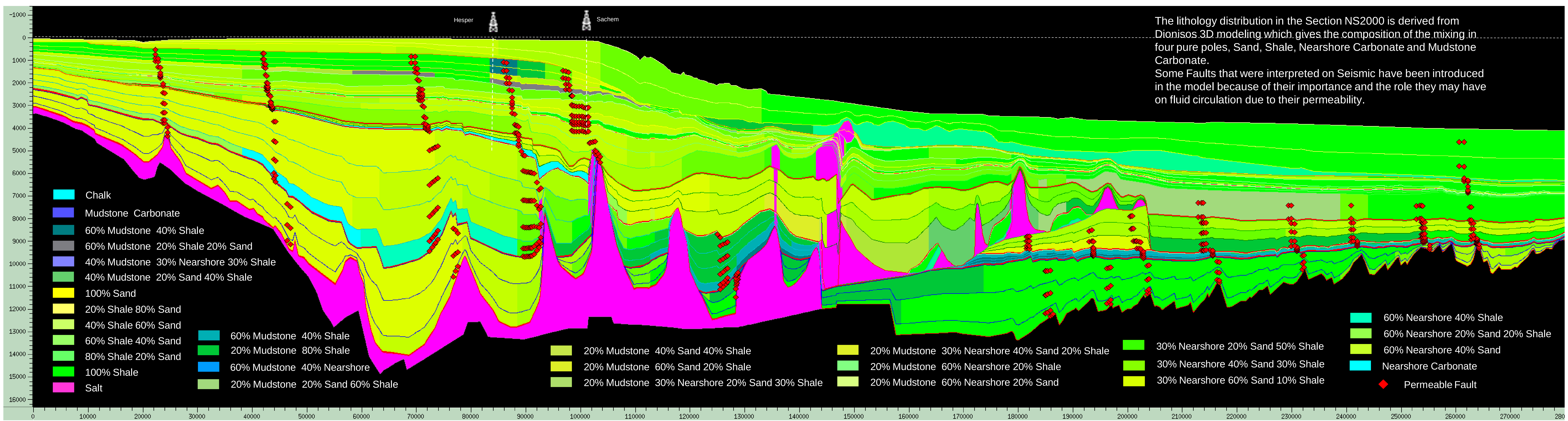


Figure 1: Lithology and Fault zones of Section NS2000 at Present day

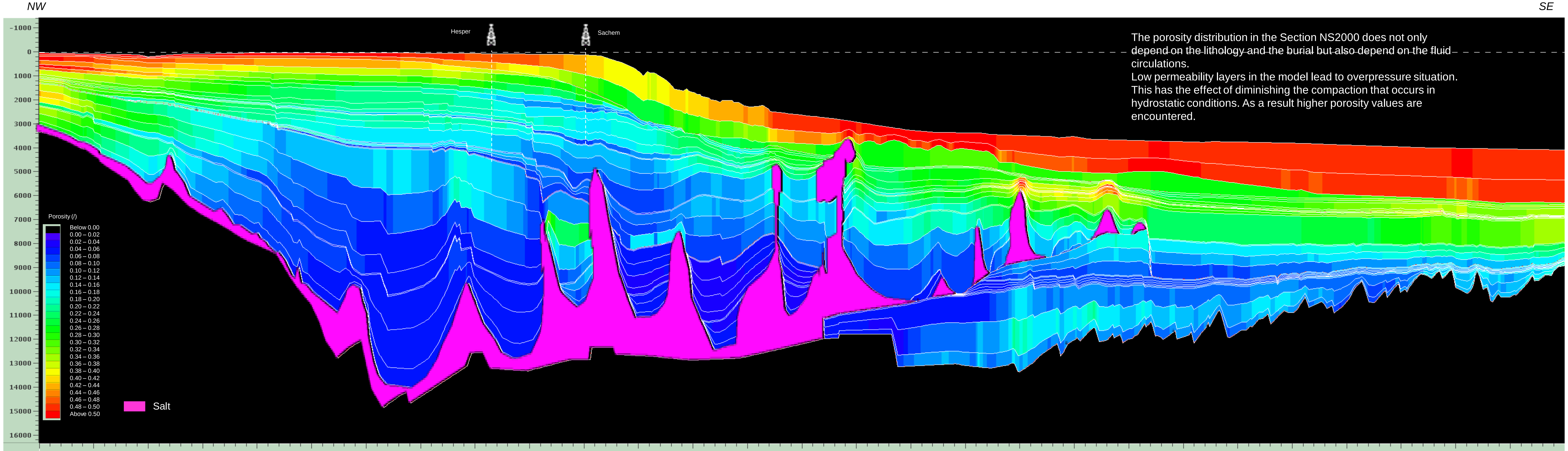


Figure 2: Porosity of Section NS2000 at Present day

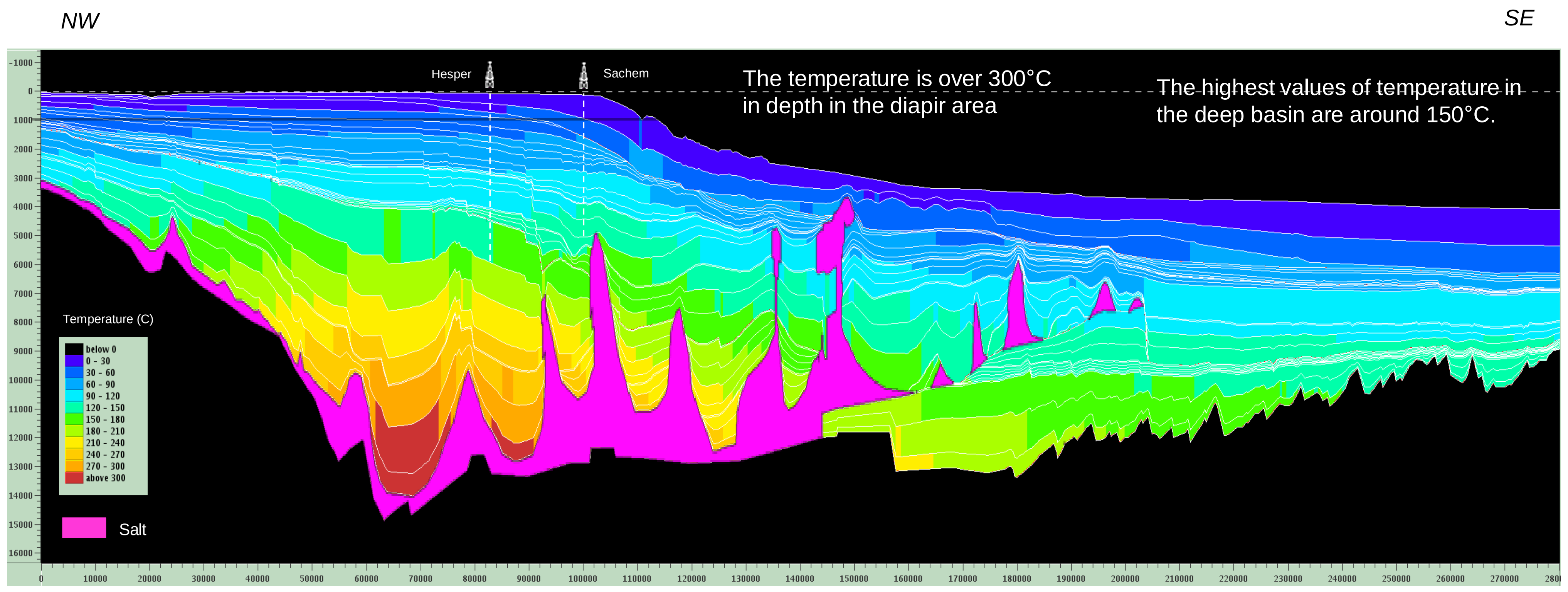


Figure 1: Temperature Field

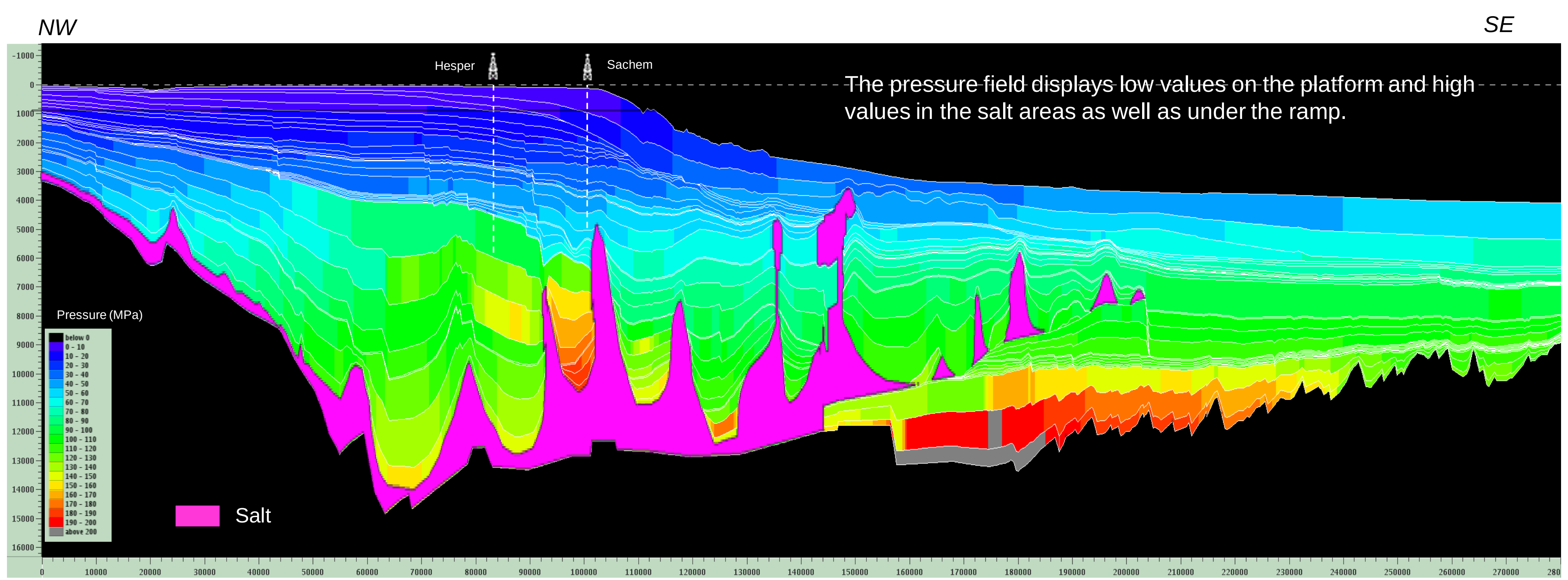


Figure 2: Pressure Field

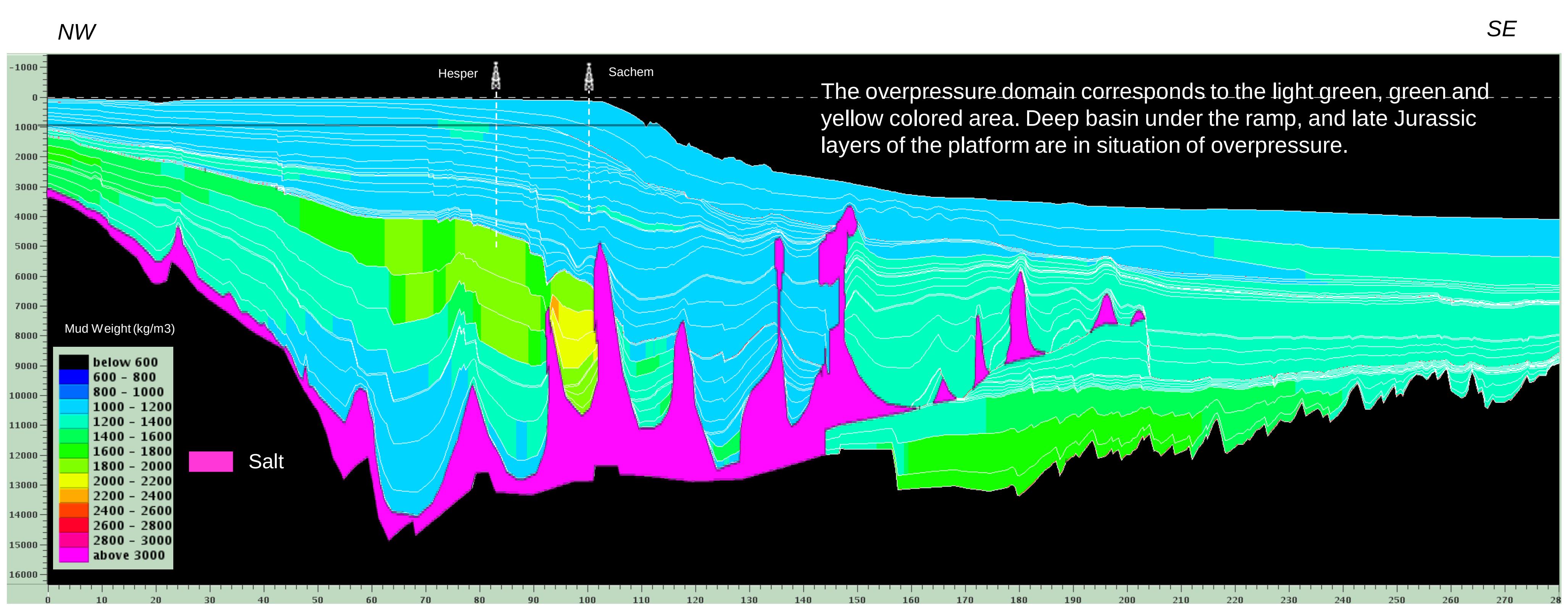
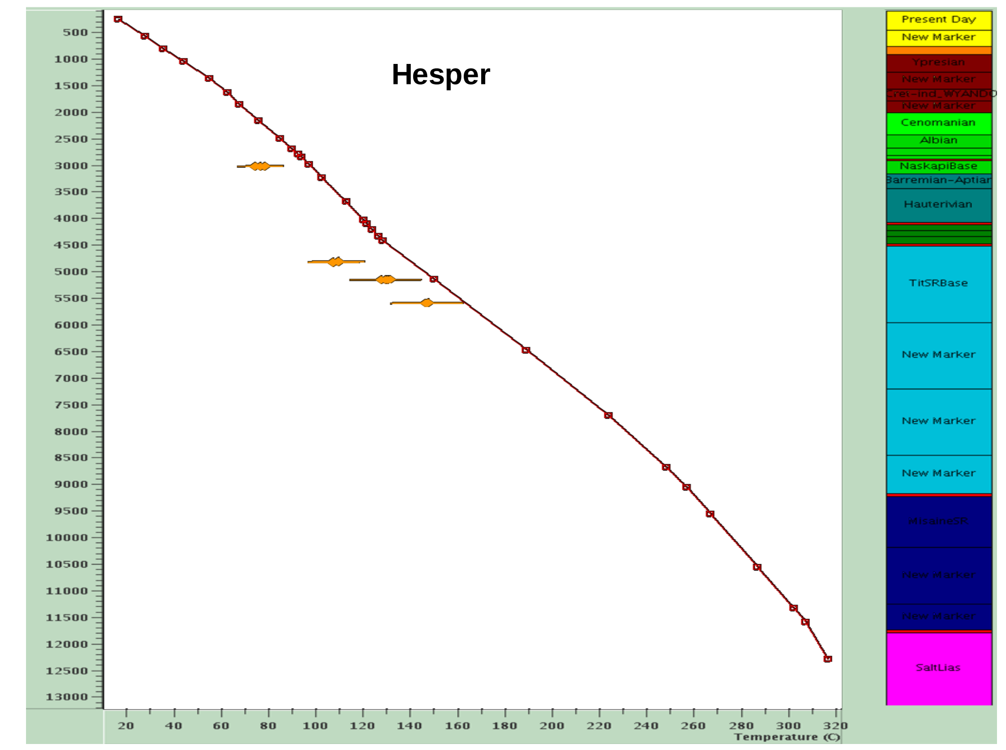


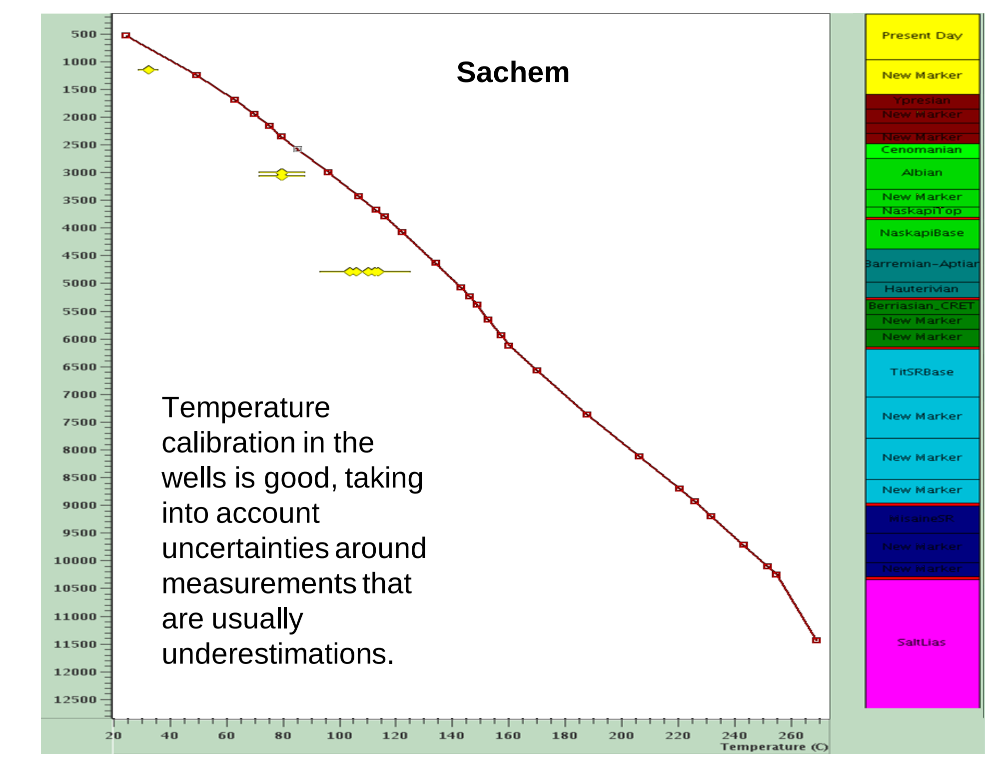
Figure 3: Mud Weight Field

Temperature Calibration

Modeled curve

Measured values in Well

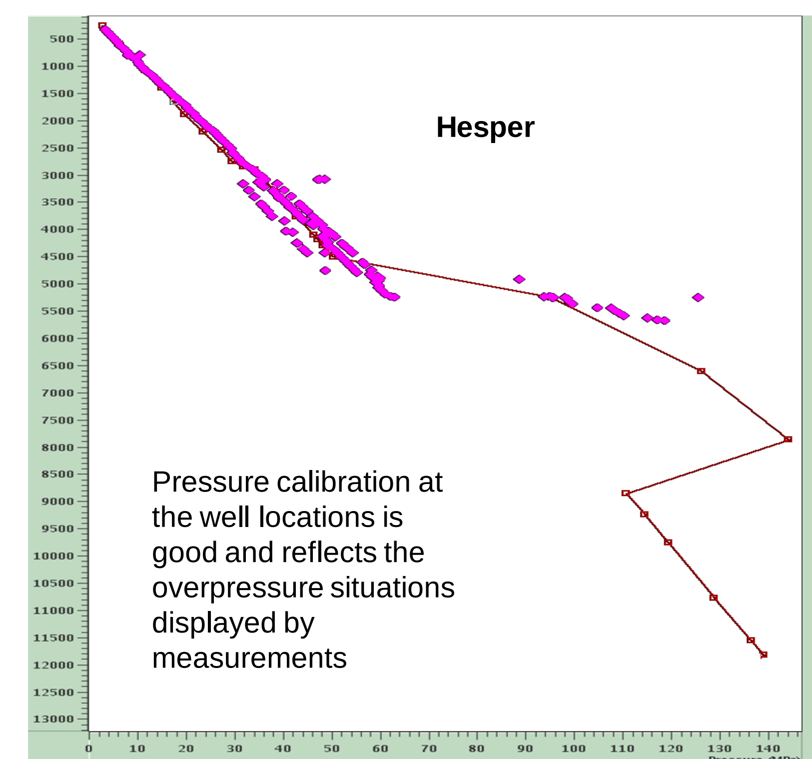


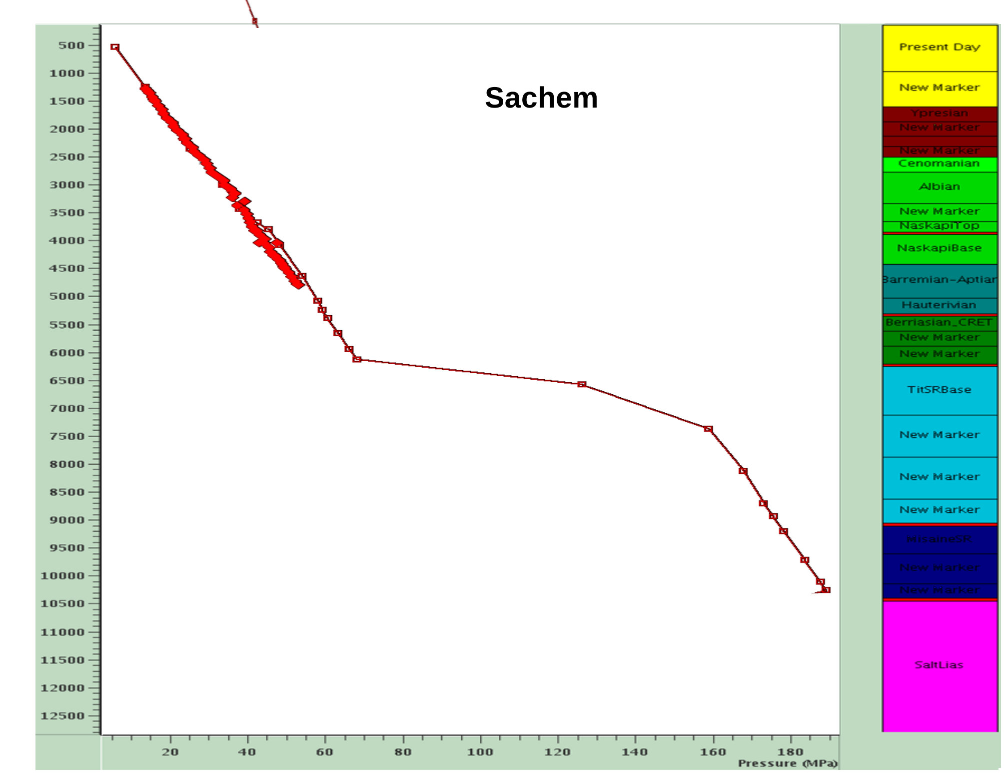


Pressure Calibration

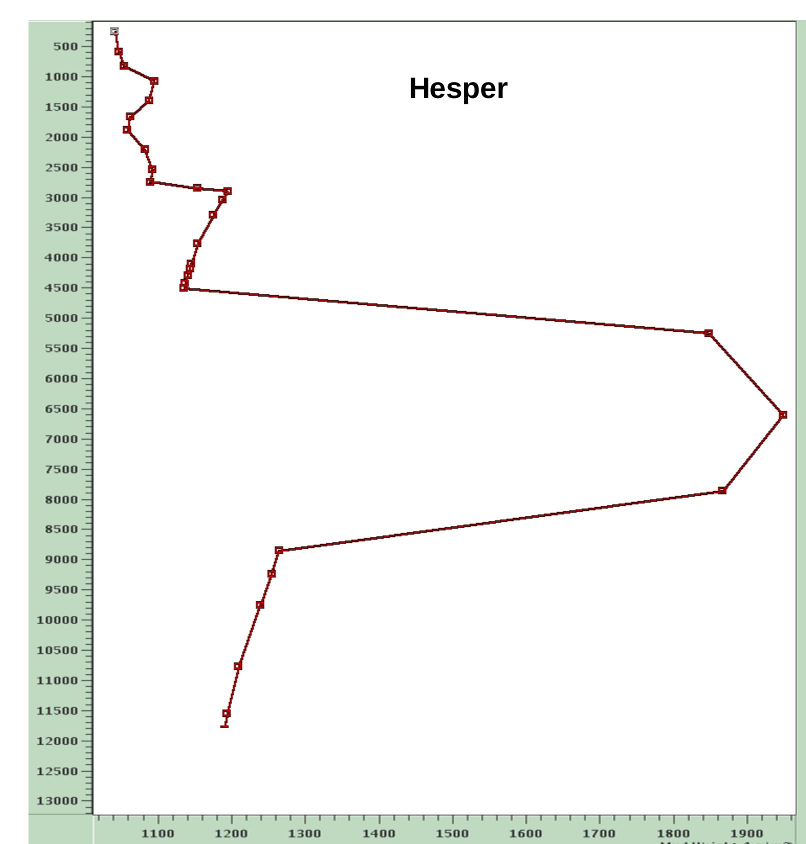
Modeled curve

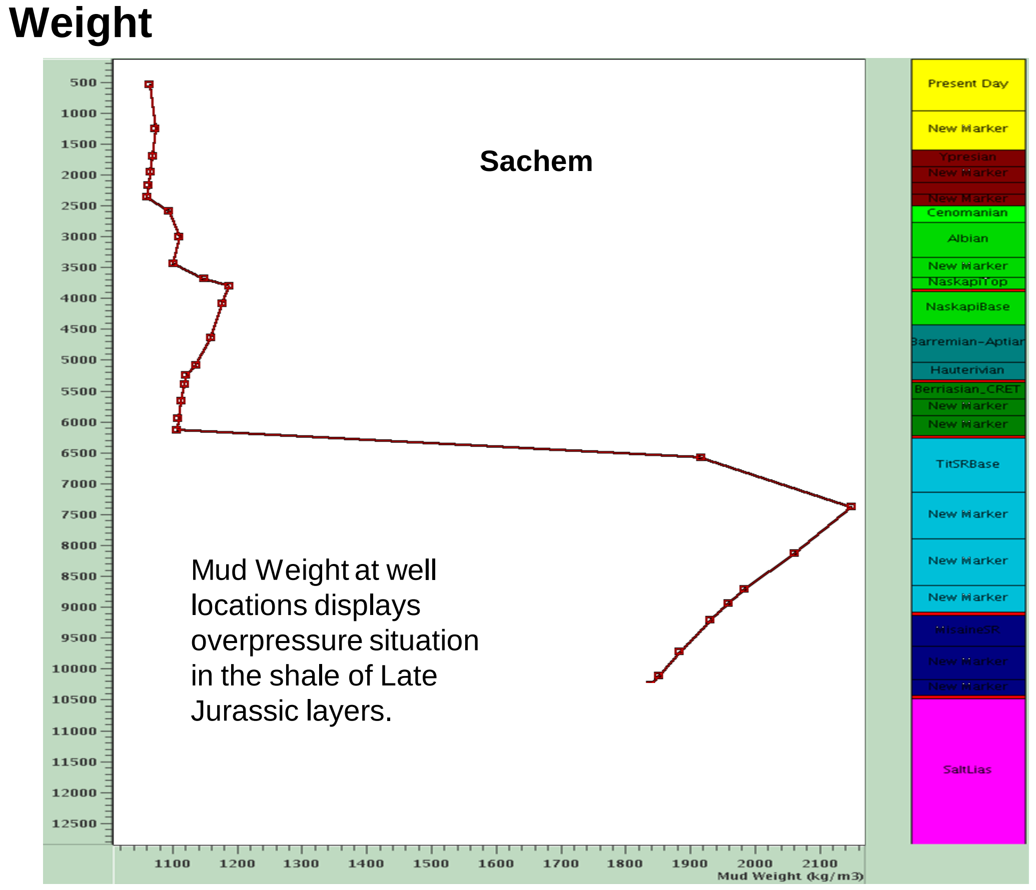
Measured values in Well





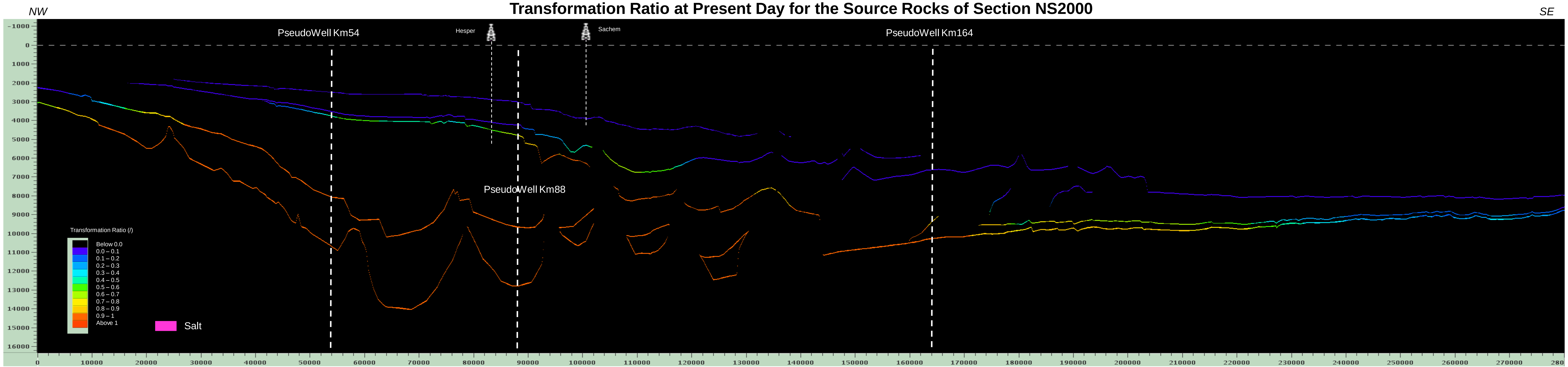
Mud Weight



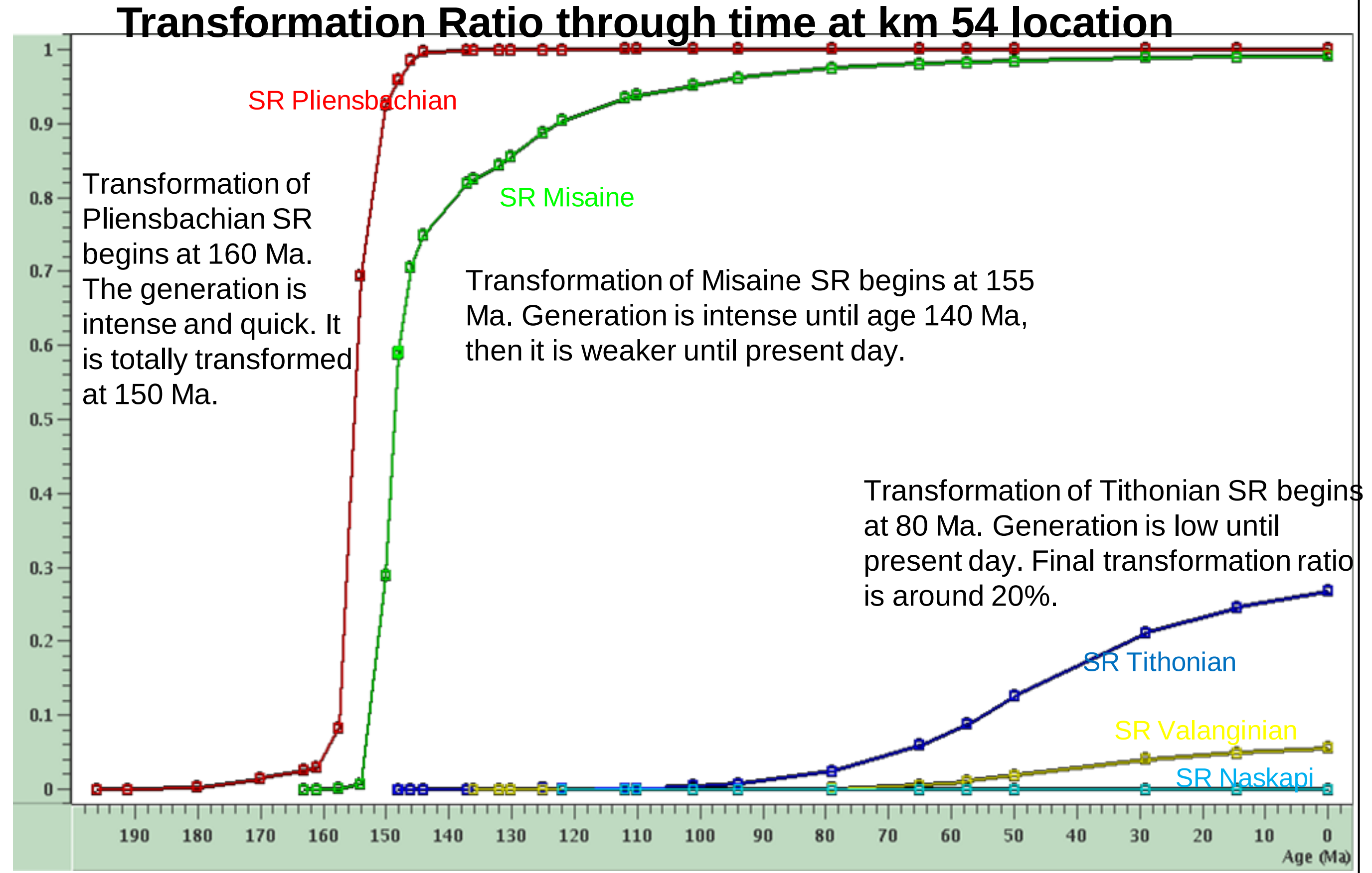


Thermodynamic Fields an Calibration of Section NS2000

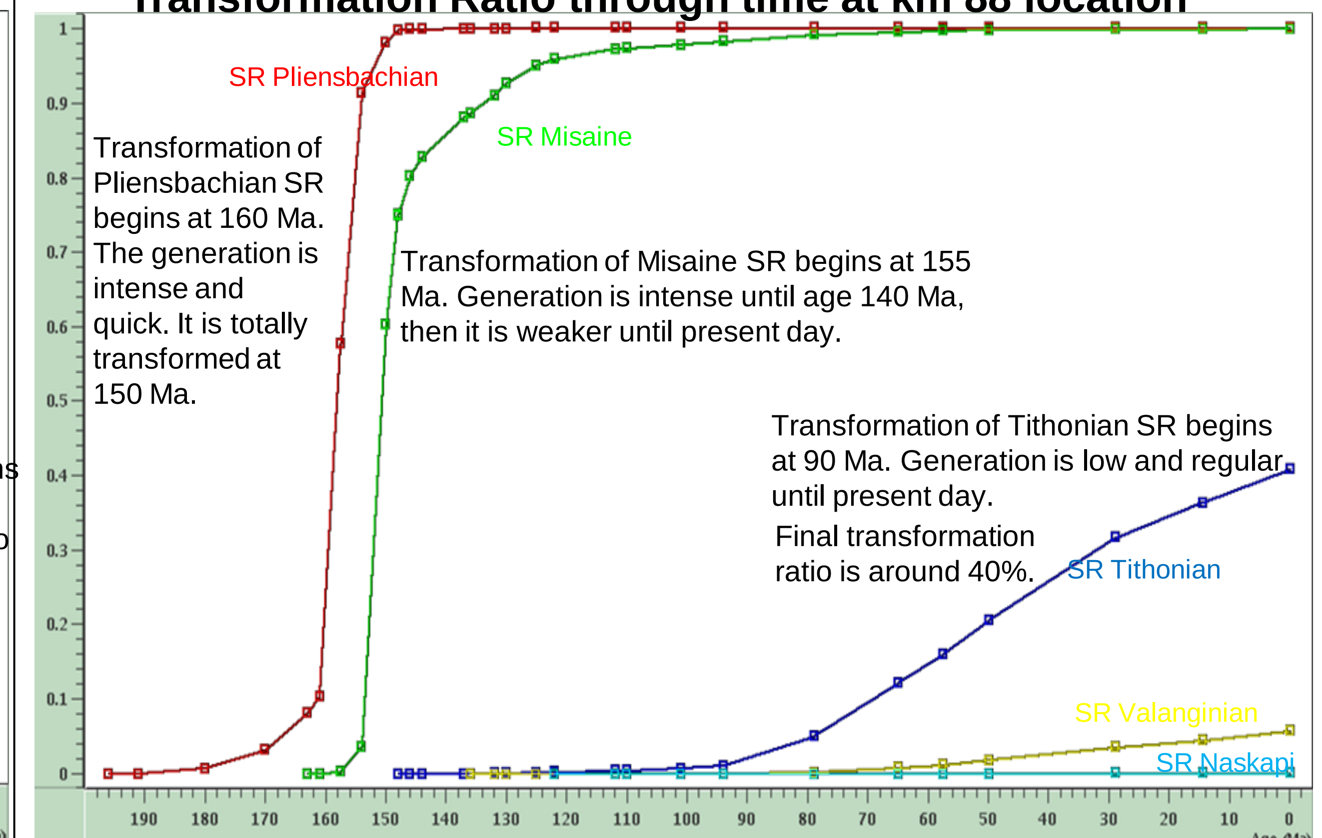
Transformation Ratio at Present Day for the Source Rocks of Section NS2000



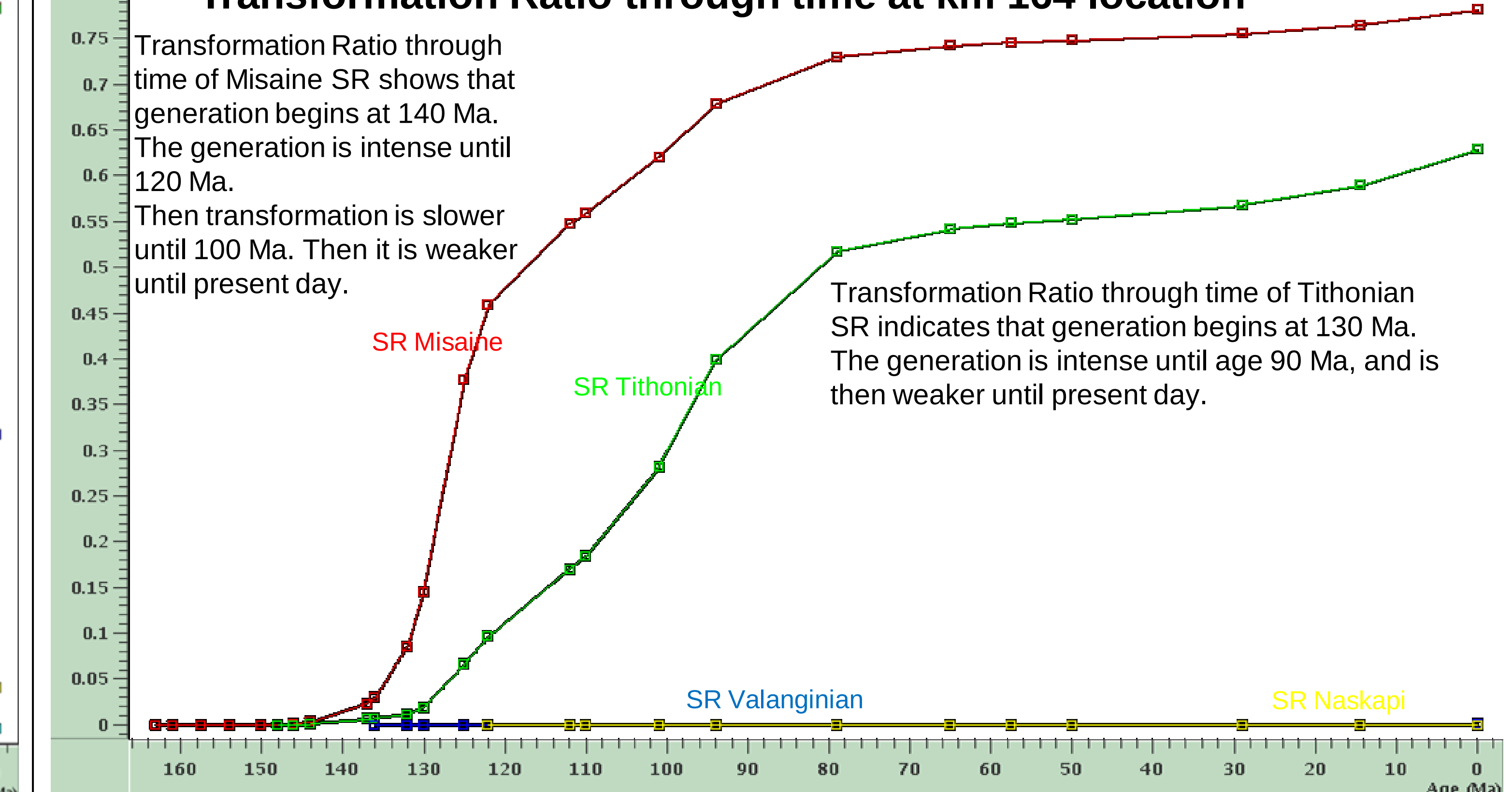
Transformation Ratio through time at km 54 location



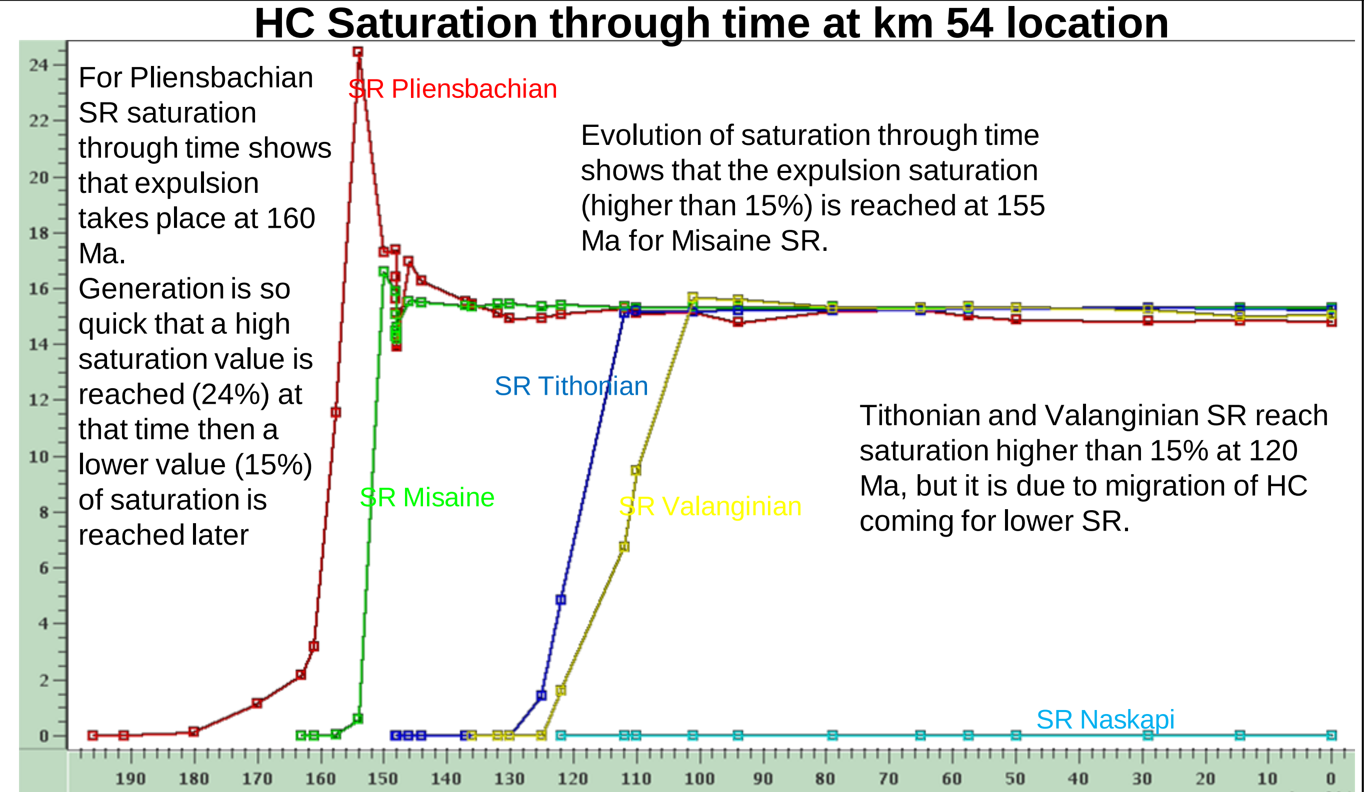
Transformation Ratio through time at km 88 location



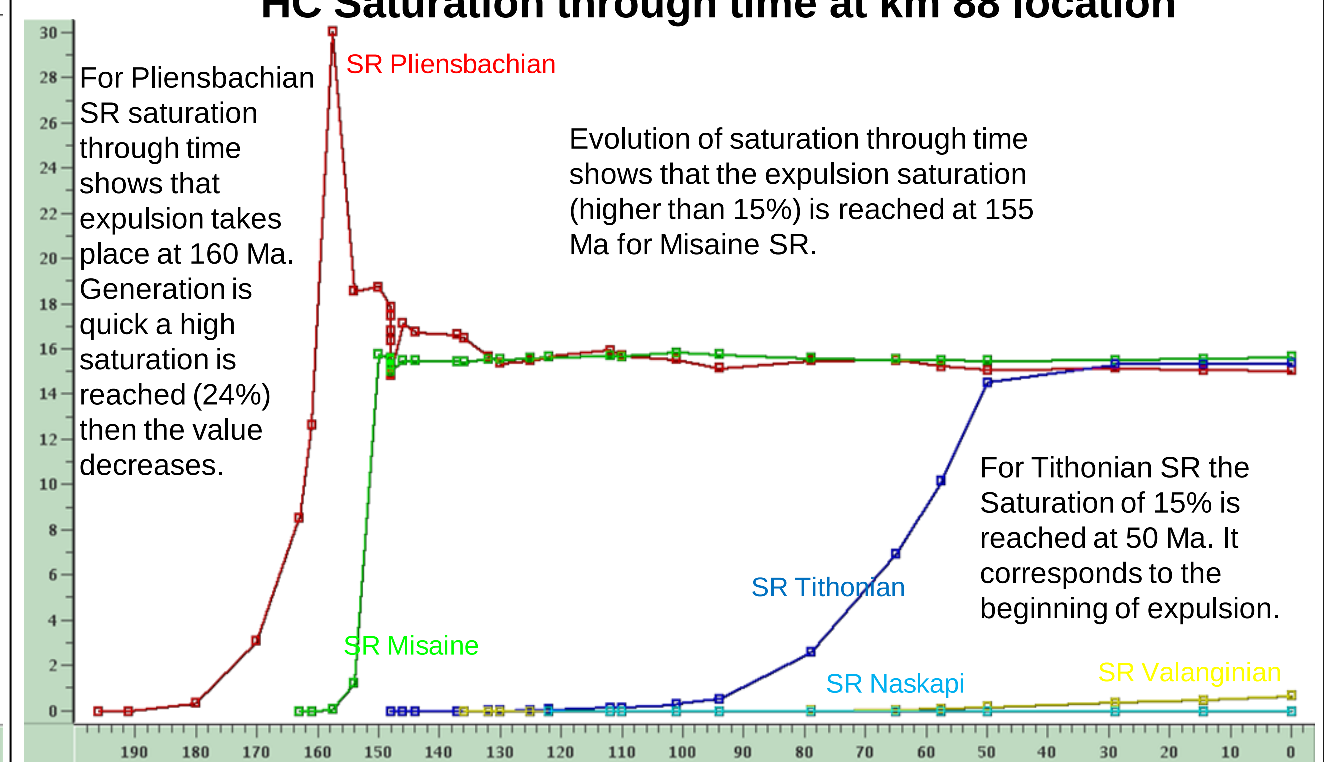
Transformation Ratio through time at km 164 location



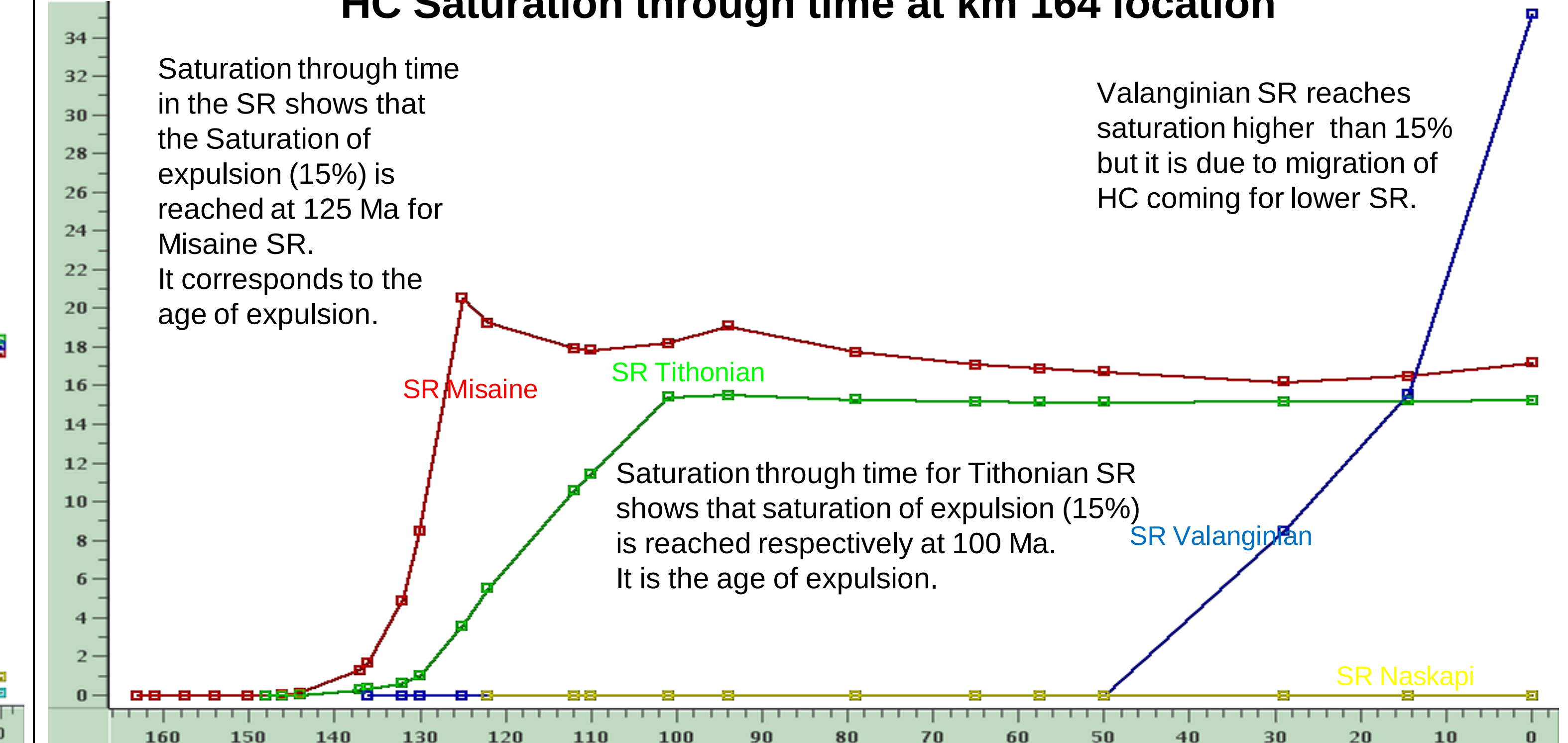
HC Saturation through time at km 54 location



HC Saturation through time at km 88 location



HC Saturation through time at km 164 location



BASIN MODELING – TEMIS 2D

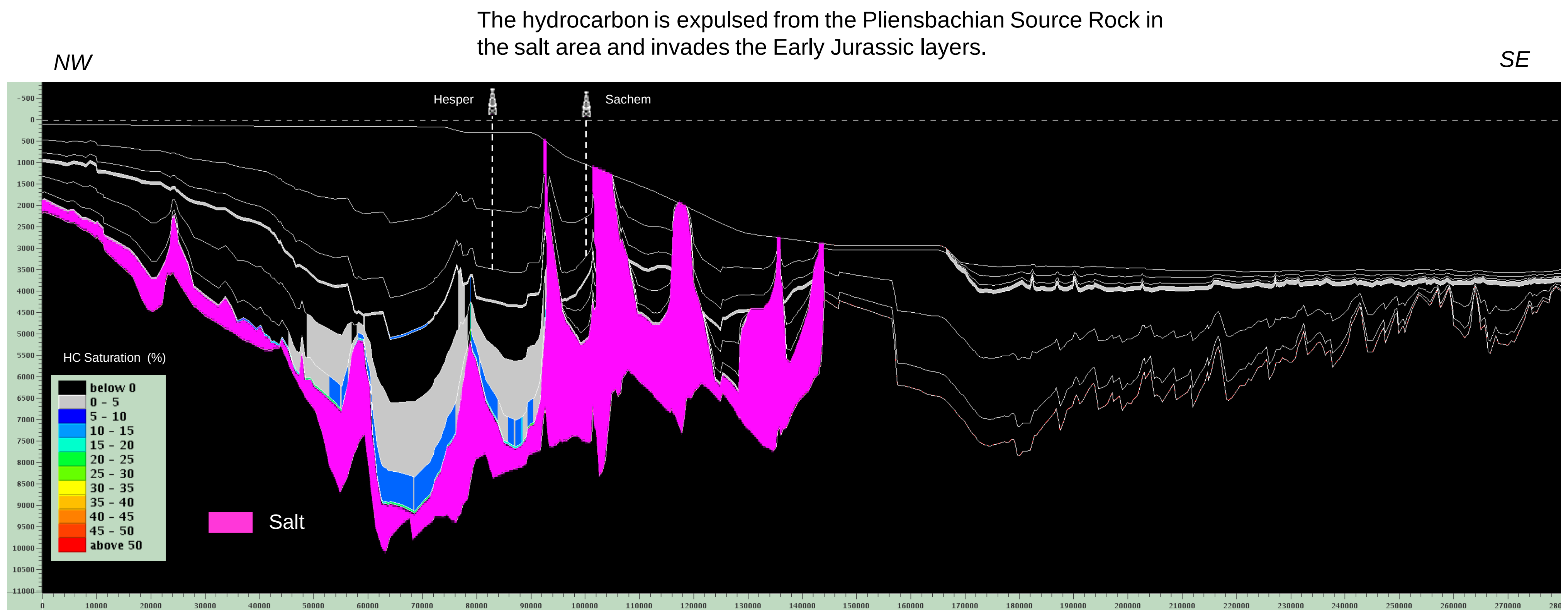


Figure 1: Kimmeridgian - 154 Ma

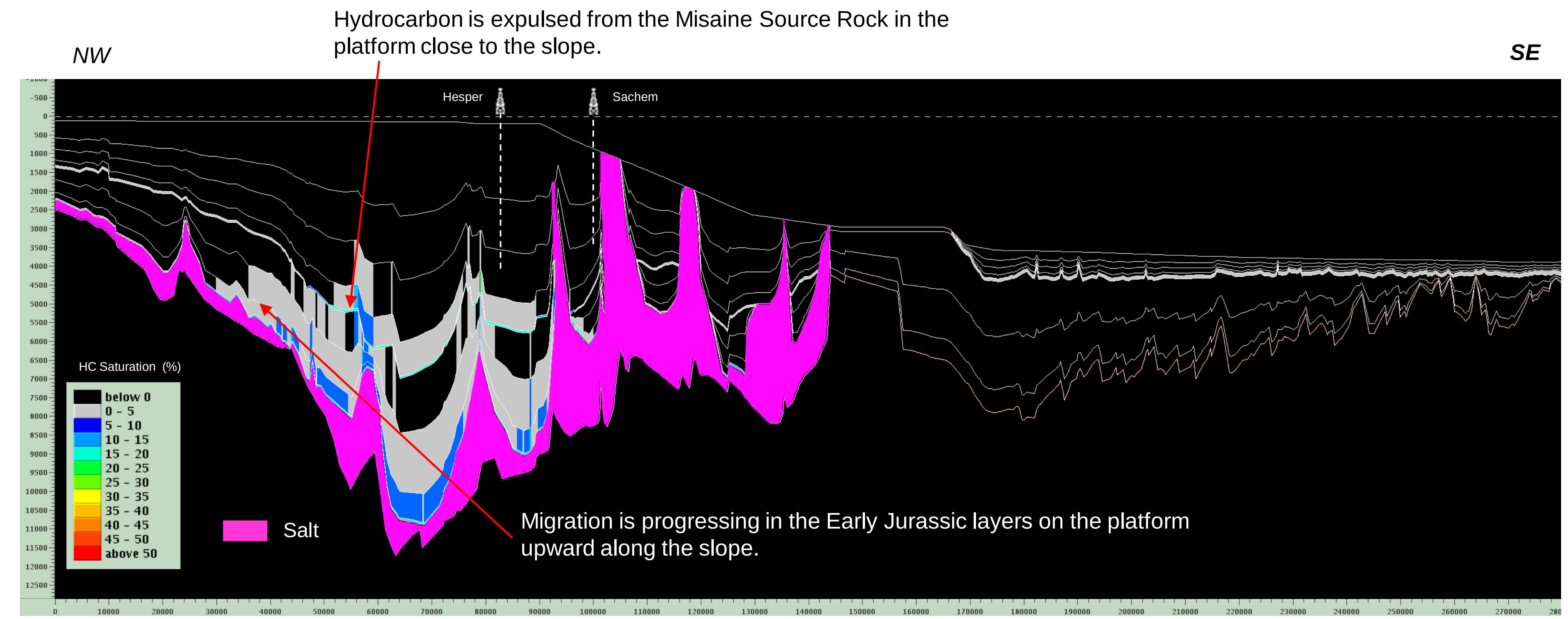


Figure 2: Tithonian - 150 Ma

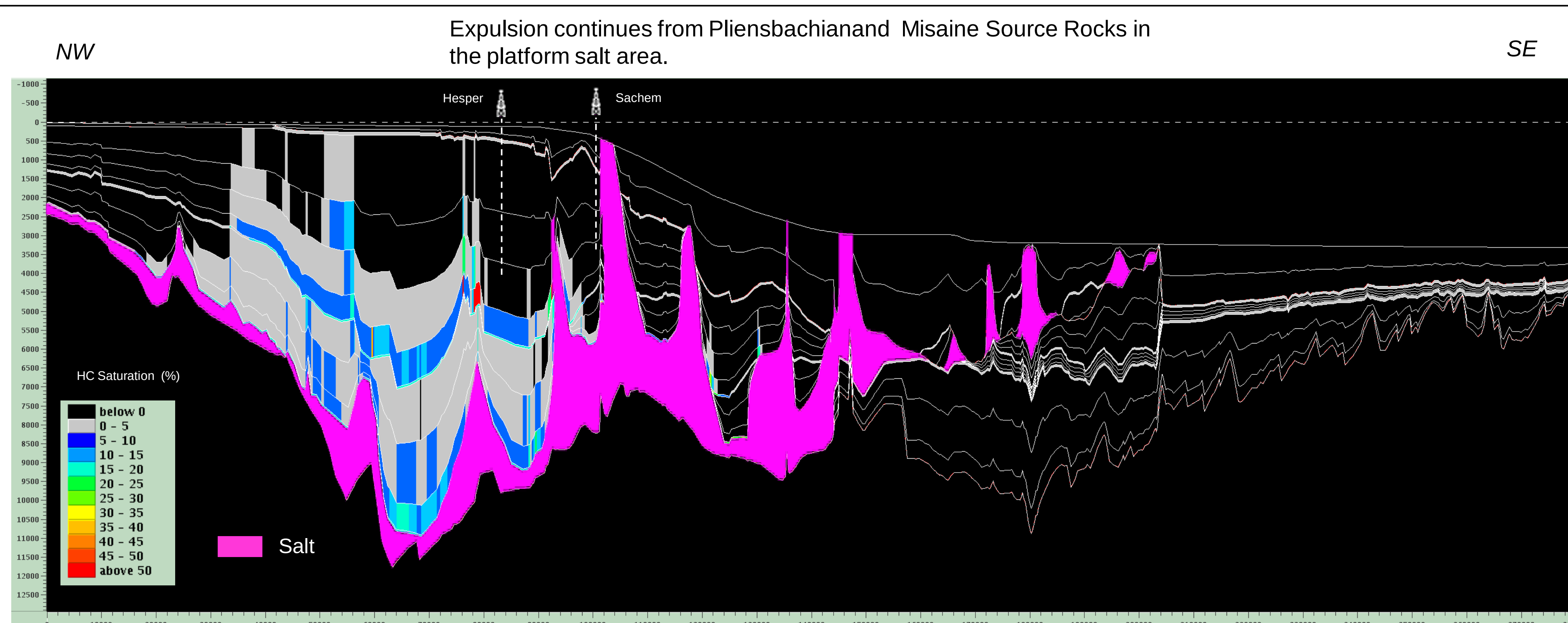


Figure 3: Berriassian - 144 Ma

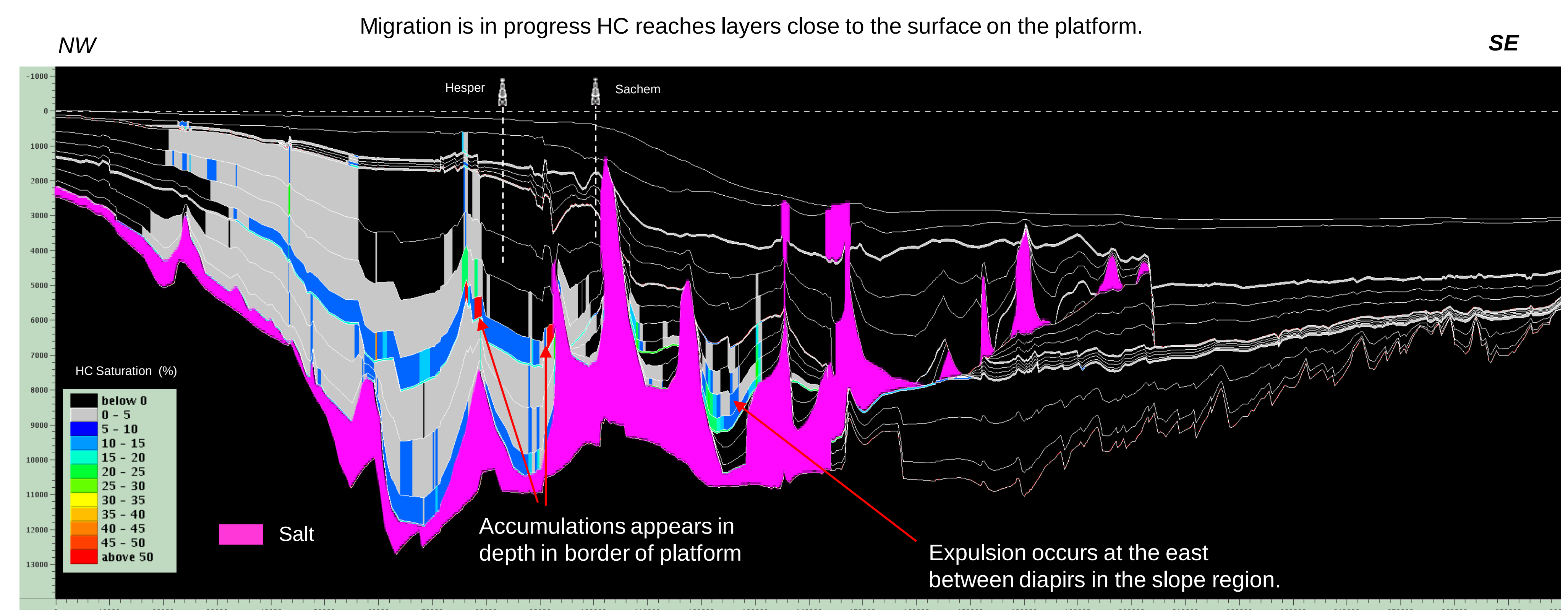


Figure 4: Hauterivian- 130 Ma

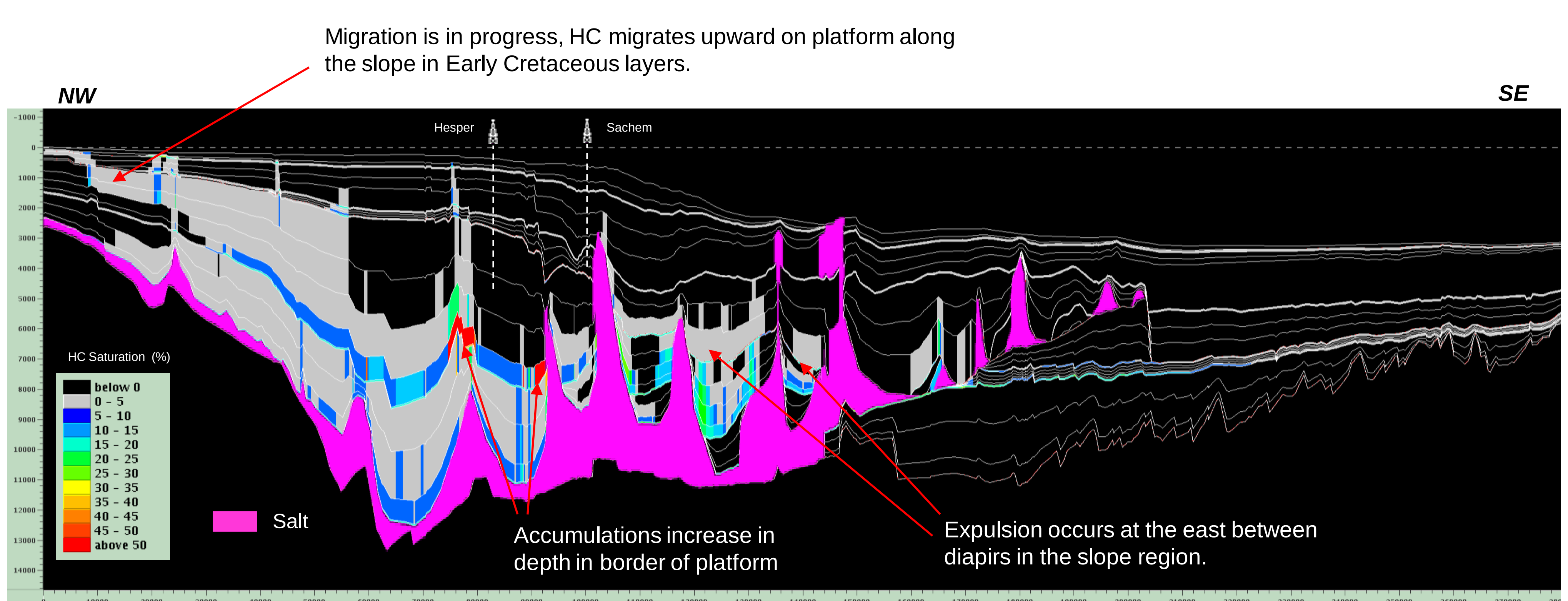


Figure 5: Aptian - 110 Ma

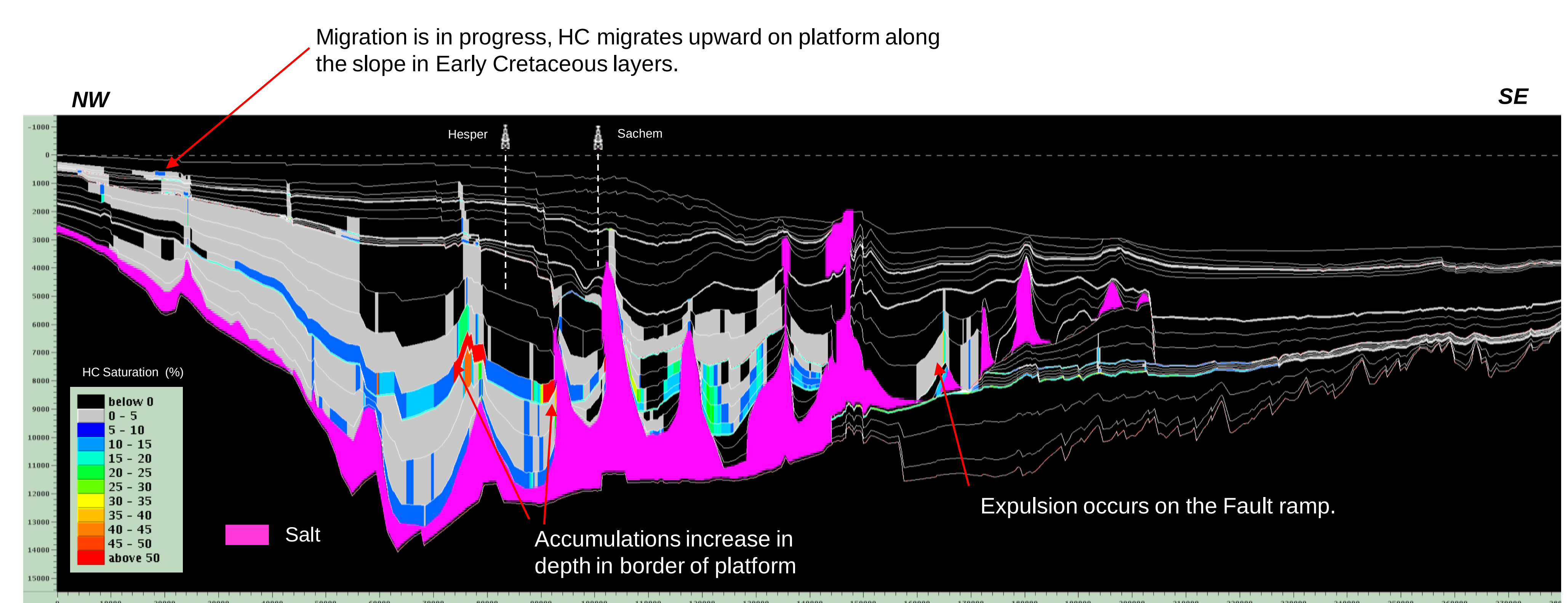


Figure 6: Cenomanian – 94 Ma

HC Saturation through time of Section NS 2000

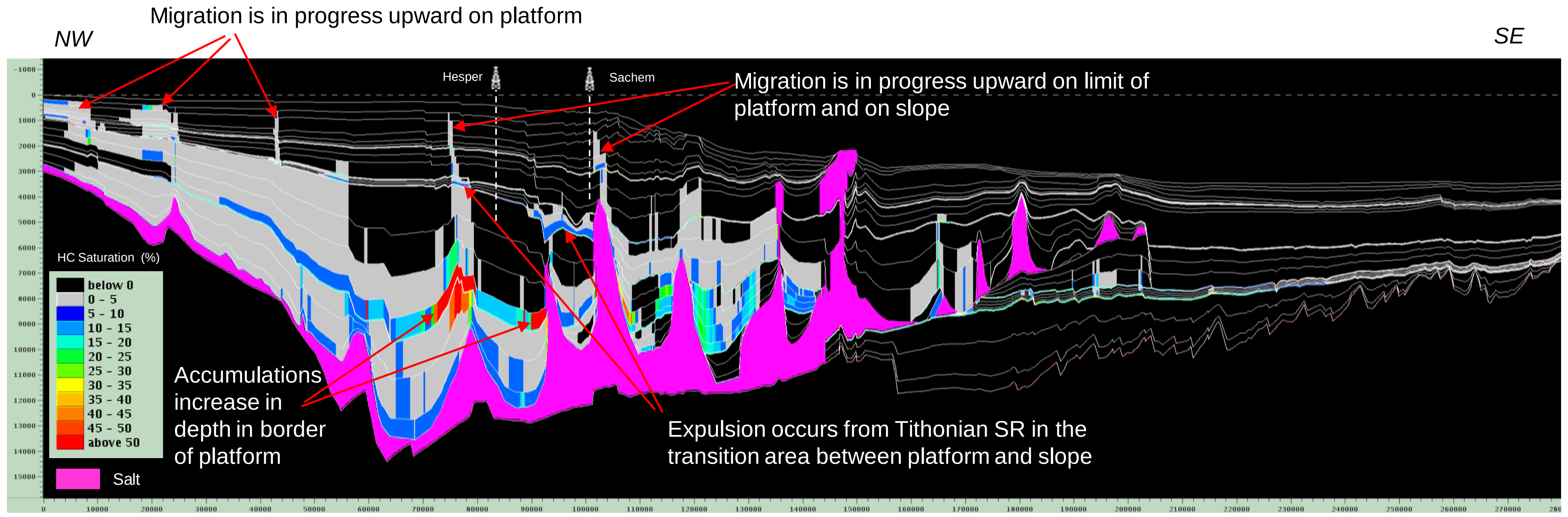


Figure 1: Maastrichtian - 65 Ma

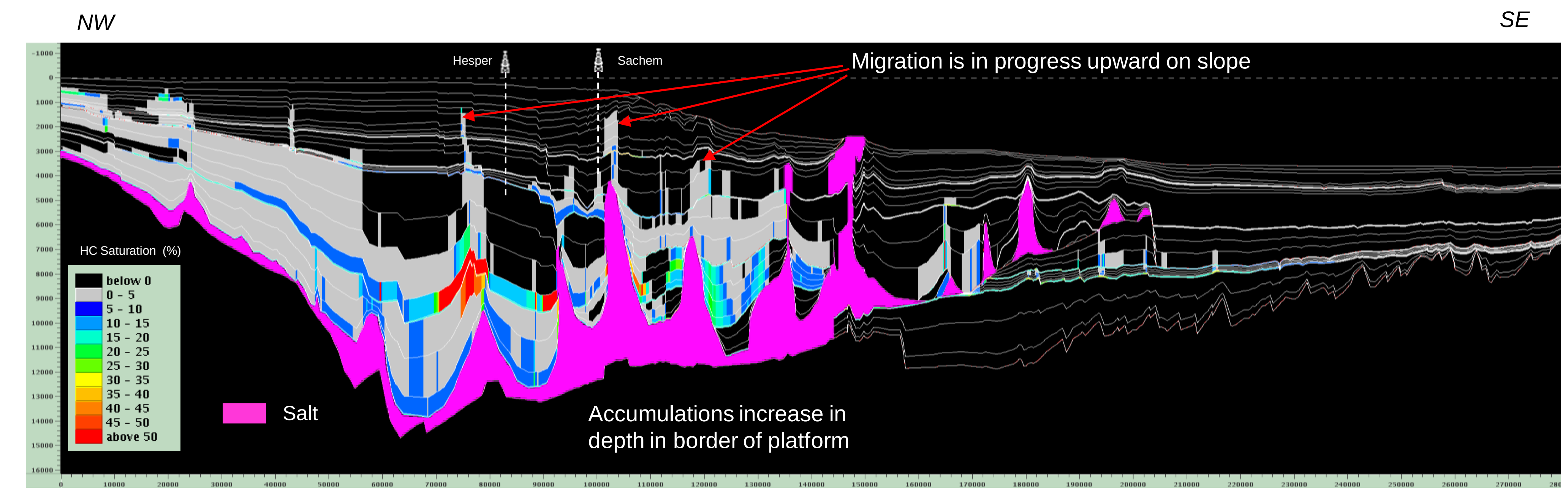


Figure 2: Ypresian - 50 Ma

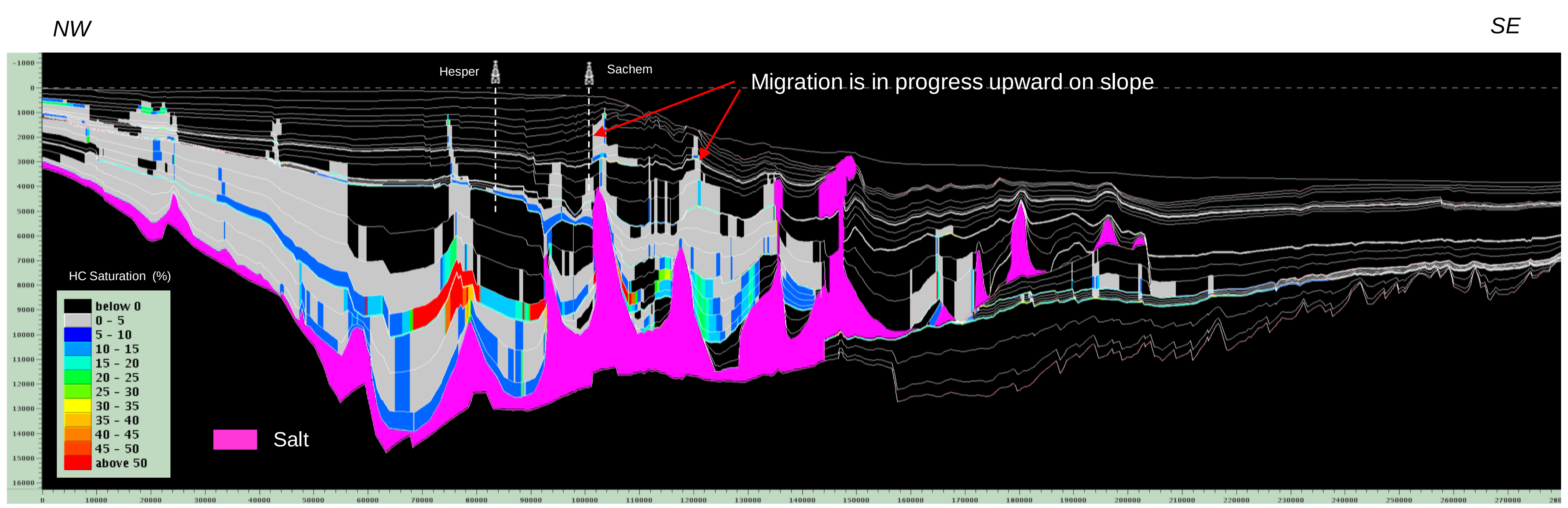


Figure 3: Rupelian - 29 Ma

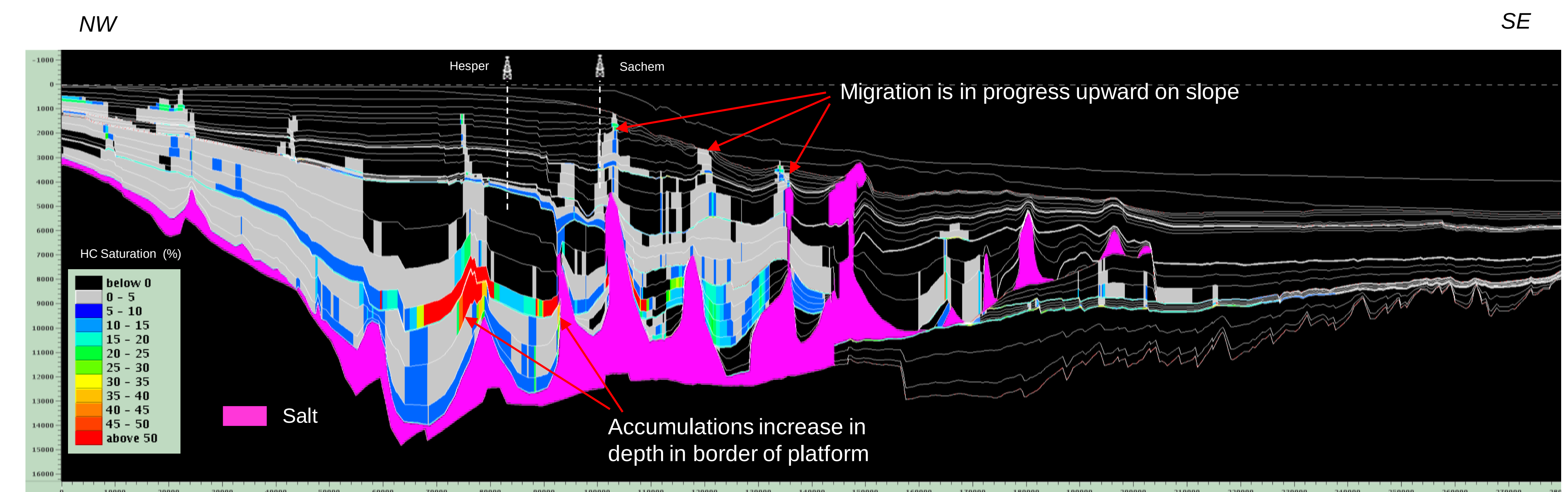


Figure 4: Langhian – 14.5 Ma

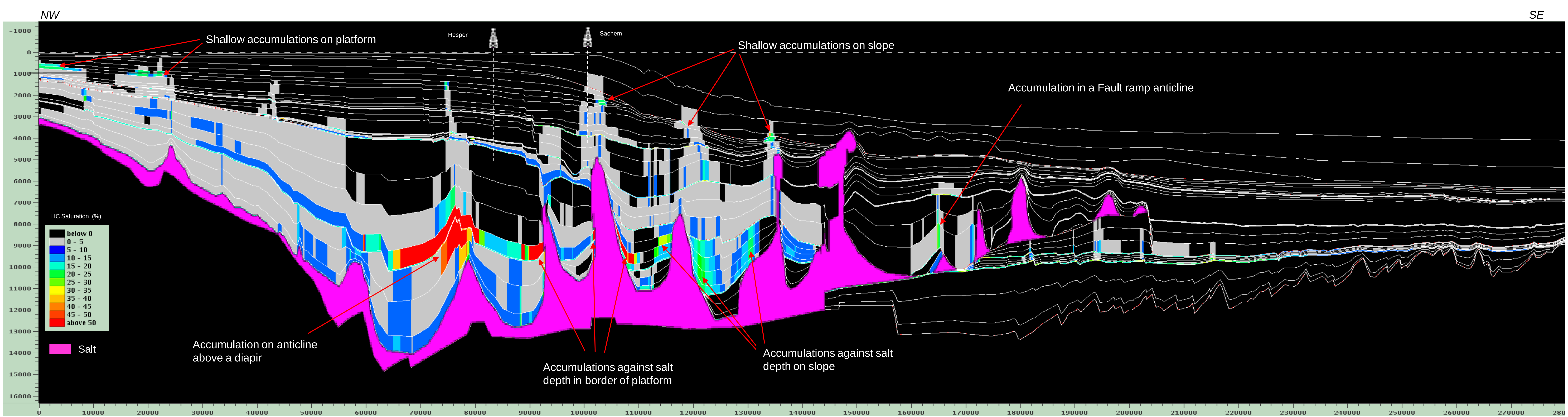


Figure 5: Present day – 0 Ma

BASIN MODELING – TEMIS 2D

The maturity field at present day let us define the oil window, gas window and over mature area in the section. The slope and the platform close to the slope are the domains the more in depth, gas window and over mature area represent a large proportion of these domains.
The deepest part of the basin and the north of the platform belong to the oil window.

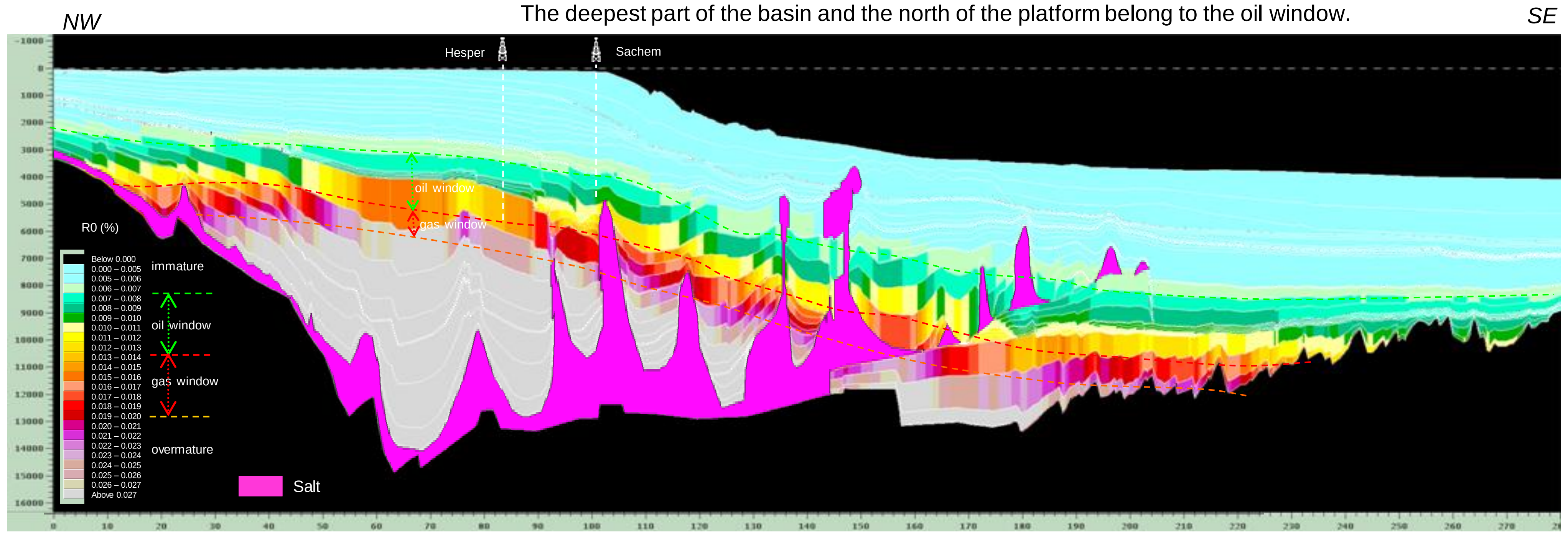


Figure 1: R0 Maturity

Some shallow accumulations are more than 4000 kg/m² locally on platform.

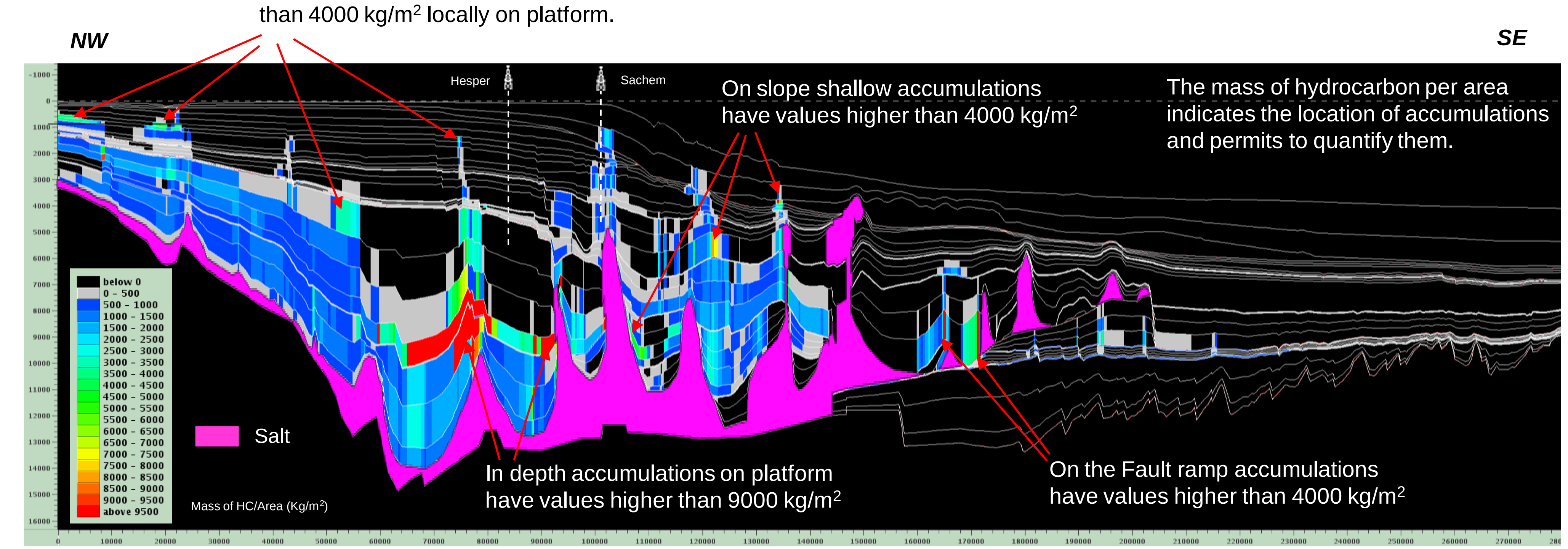


Figure 2: Total HC Mass

The mass fraction of gas higher than 500 kg/m² corresponds to the blue color area, it corresponds also to the area where hydrocarbon is present in the section. This means that gas is the majority fraction of hydrocarbon in the domain.

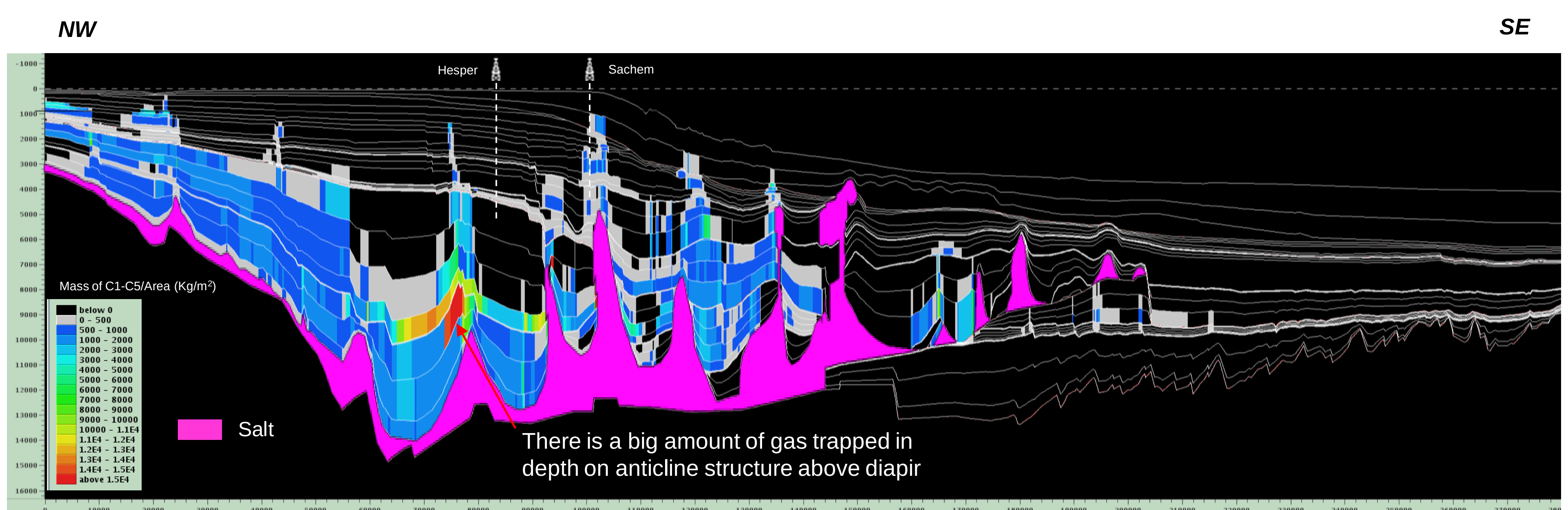


Figure 3: Fraction C1-C5

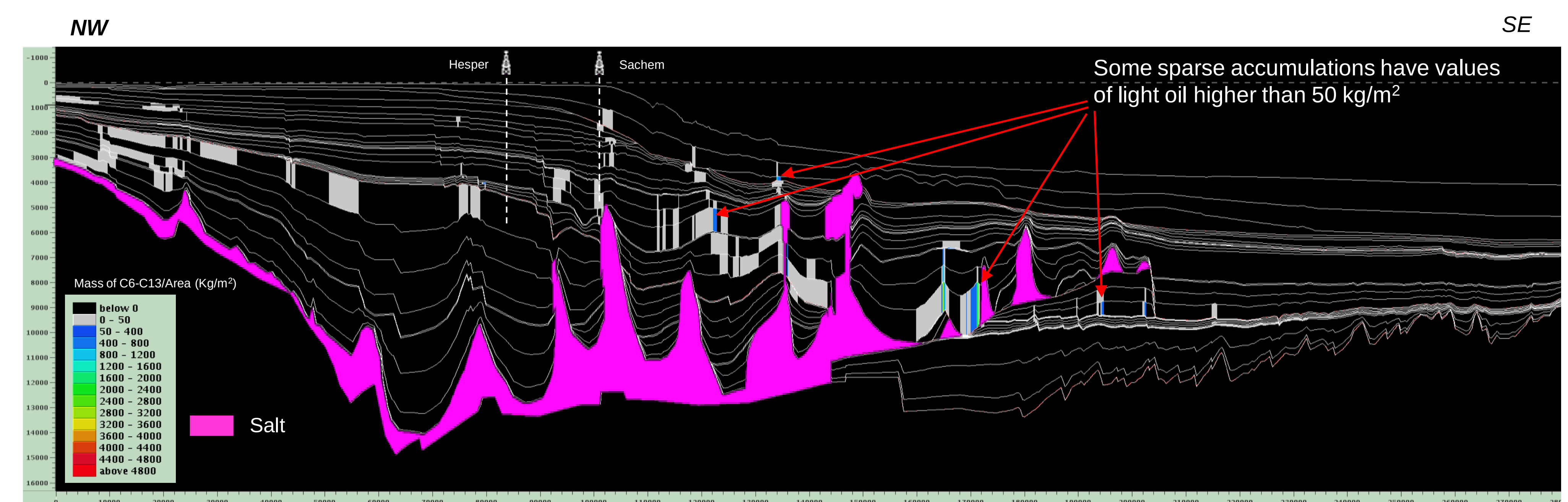


Figure 4: Fraction C6-C13

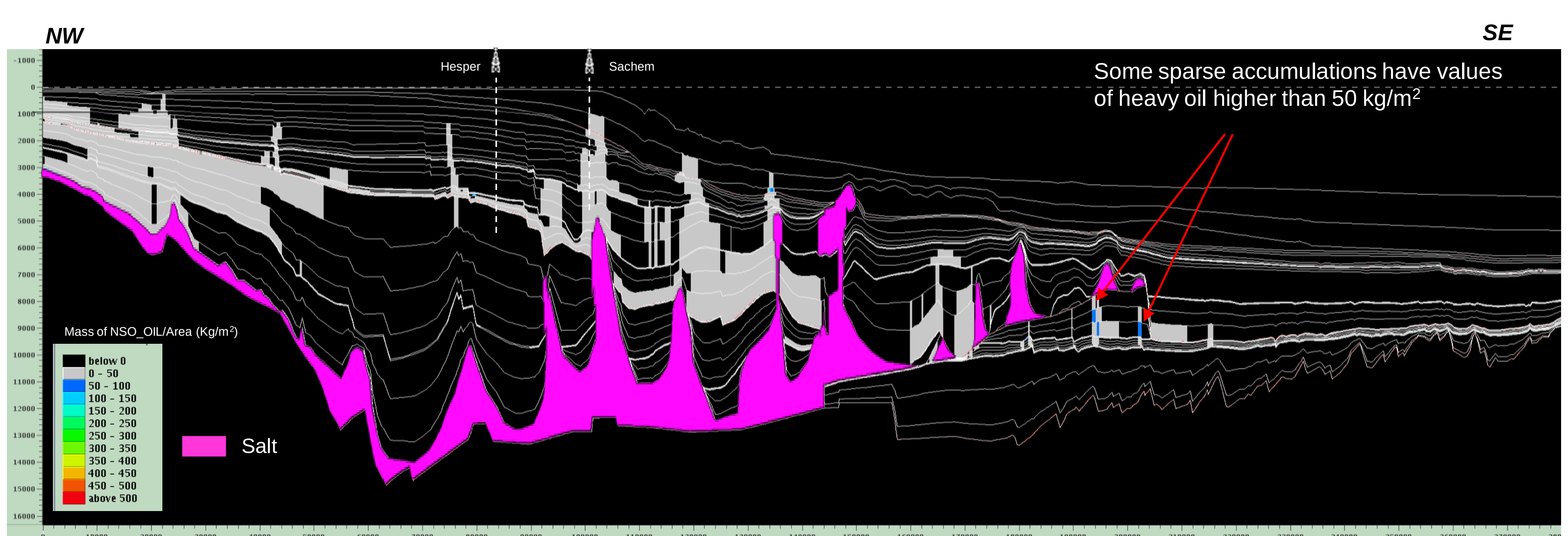


Figure 5: Fraction Nitrogen / Sulfur / Oxygen OIL

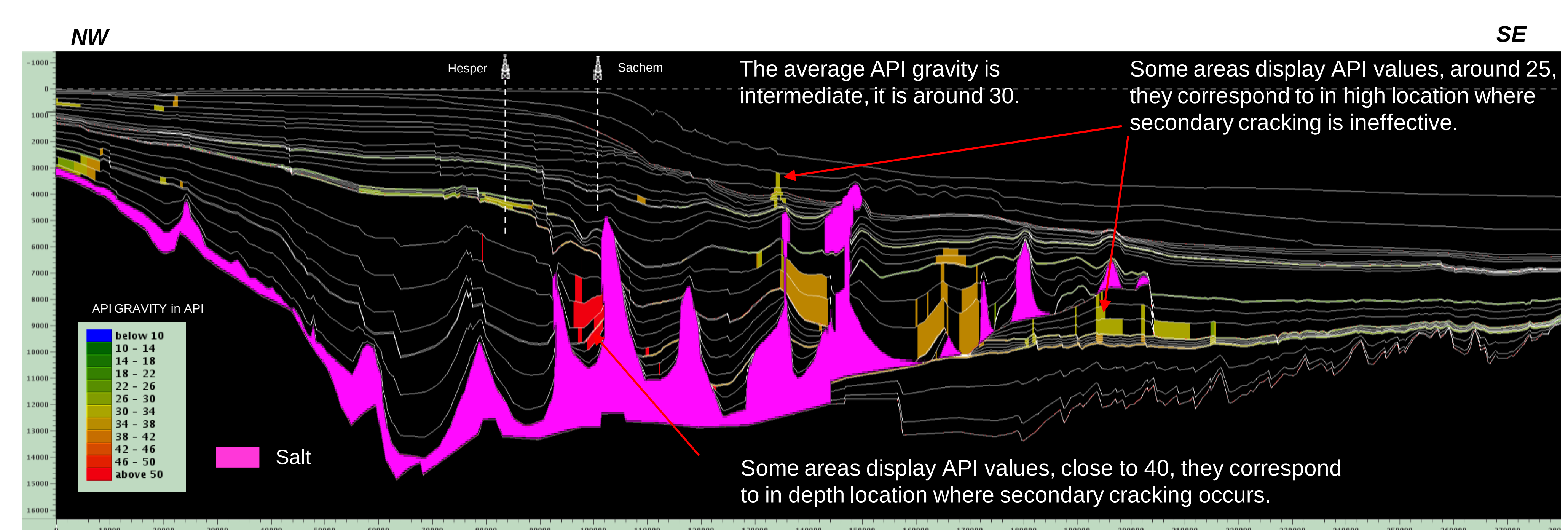
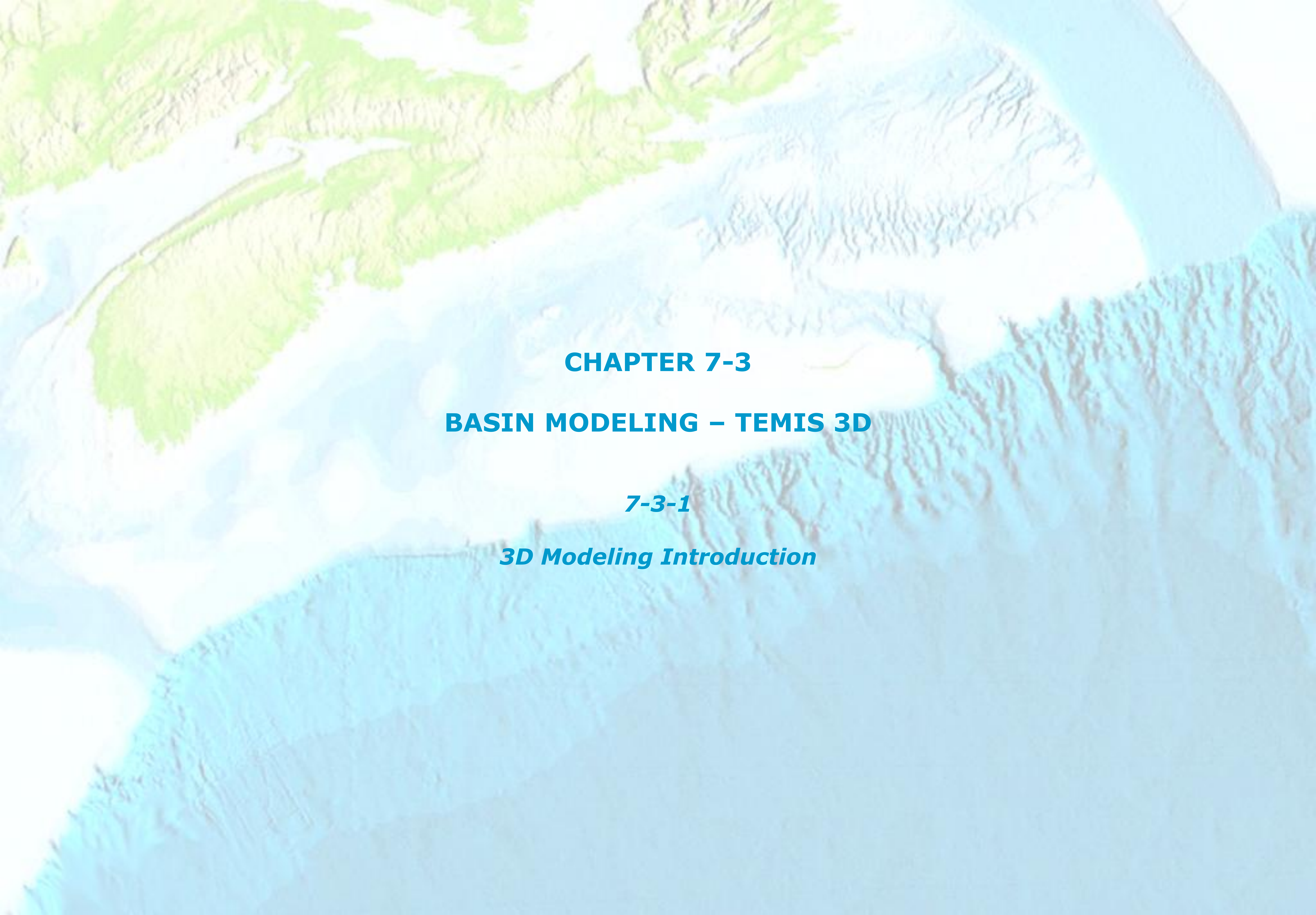


Figure 6: API Gravity

PL. 7-2-5-5 **Maturity, Fractions and HC Quality at present day of Section NS2000**



CHAPTER 7-3

BASIN MODELING – TEMIS 3D

7-3-1

3D Modeling Introduction

Play Fairway Analysis Offshore Nova Scotia
TEMIS 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 in 6 subzones / 5 plays**

Results will be used for building **CRS maps**, and for the **Yet to Find analysis**.

→ Tools:

- The basin modeling software Temis 3D®
- Migration tools "Drain" and "PetPot" (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.)
- Temis 2D® results (calibration data and migration efficiencies)

Table of Content

Resolution of TEMIS 3D Blocks used for this study

→Reference 3D Block, from seismic interpretation:

- 741*451 meshes (topo grid)
- mesh resolution 1000 * 1000 m (maximum)
- 28 layers (29 horizons)

→ 3D Block for Temis / Maturity Modeling:

- 297*181 meshes
- mesh resolution 2500 * 2500 m
- 28 layers (29 horizons)

→ 3D Block for Play System modeling (modules "Drain" and "PetPot")

- 741*451 meshes (topo grid)
- mesh resolution 1000 * 1000 m (maximum)
- 14 layers (15 horizons)

5 PLAY SYSTEMS and 5 SOURCE ROCKS are studied:

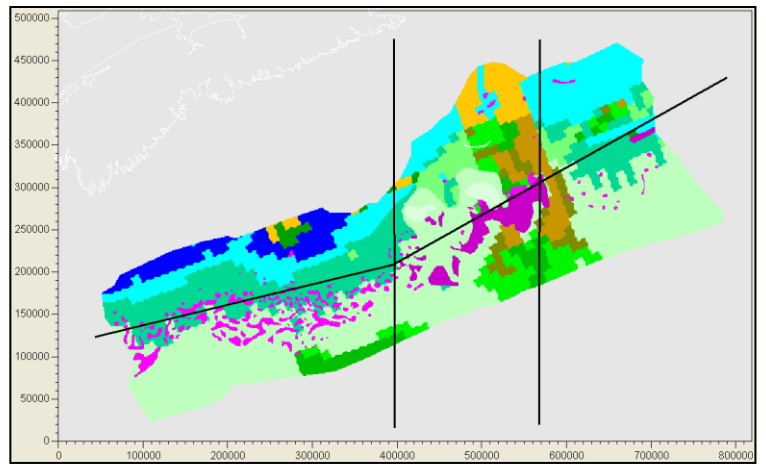
PLAY SYSTEMS	*SOURCE ROCKS*
Albian-Cenomanian (K112-K94)	APTIAN SR (~C122)
Hauterivian-Barremian (K130-K123)	VALANGINIAN SR (~C136)
Berriasian-Valanginian-Hauterivian (J150-K130)	TITHONIAN SR (~J148)
Oxfordian-Tithonian (J163-J150)	CALLOVIAN SR (~J160)
Early-Middle-Jurassic (J200-J163)	PLIENSBACHIAN SR (~J196)

Stratigraphic chart in the Reference 3D Block

11 horizons provided by geophysicists are used in the models. Other horizons correspond to subdivisions with limited geological constraints.
For more details on source rocks and play systems/reservoirs, see PL. 7-3-1-3 and PL. 7-3-1-4.

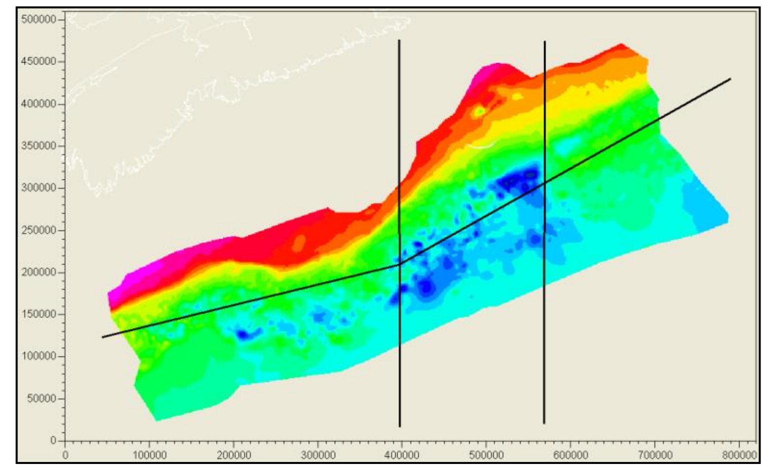
Age (horizon)	Horizon	Play Systems	Top "Virtual" Reservoirs in the 3D block	Top Source Rocks in the 3D block	Seismic Horizons (from interpretation)	Horizon Color
0	**Sea Bottom**					
14.5	Miocene (~mid Miocene)				*subdivision*	
29	**Oligocene UNCONFORMITY (~mid Oligocene)**					
50	**Eocene (~base Eocene)**					
70	Top Chalk				*subdivision*	
94	**Cenomanian UNCONFORMITY (~top Cenomanian)**	K112-K94				
101	**Albian_Logan Canyon UNCONFORMITY (~top Albian)**					
112	Top Aptian_Logan-Cree				*Subdivision*	
122	Top Aptian SR				*Subdivision*	
125	Top Barremian_U. Mississauga	K130-K123			*Subdivision*	
127	Base "Virtual Reservoir"_U. Mississauga				*Subdivision*	
130.5	**Top Hauterivien_M. Missisauga**	J150-K130				
131.5	Base "Virtual Reservoir"_M. Mississauga				*Subdivision*	
133	Hauterivian Ind.				*Subdivision*	
136	Top Valanginian SR				*Subdivision*	
137	**BCU**					
139	Berriasian-Valanginian Ind._L. Mississauga				*Subdivision*	
145	Tithonian-Berriasian Ind._ L. Mississauga				*Subdivision*	
148	Top Tithonian SR				*Subdivision*	
150	**Top Baccaro-MicMac (Upper Jurassic)**	J163-J150				
151	Base "Virtual Reservoir"_Baccaro-MicMac				*Subdivision*	
155	Upper Jurassic Ind.				*Subdivision*	
160	Top Callovian SR				*Subdivision*	
163	**TOP-Scatarie (Middle Jurassic)**	J200-J163				
165	Base "Virtual Reservoir"_Scatarie				*Subdivision*	
170	Middle Jurassic Ind.				*Subdivision*	
196	Top Pliensbachian SR				*subdivision*	
197	**Top Autochtous Salt**					
225	**Top Basement (pre-rift)**					

Dionisos® Sedimentary Facies Maps



→ Mesh Refining (Dionisos grid resolution 10 * 10 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 (with gross sand maps)
- 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

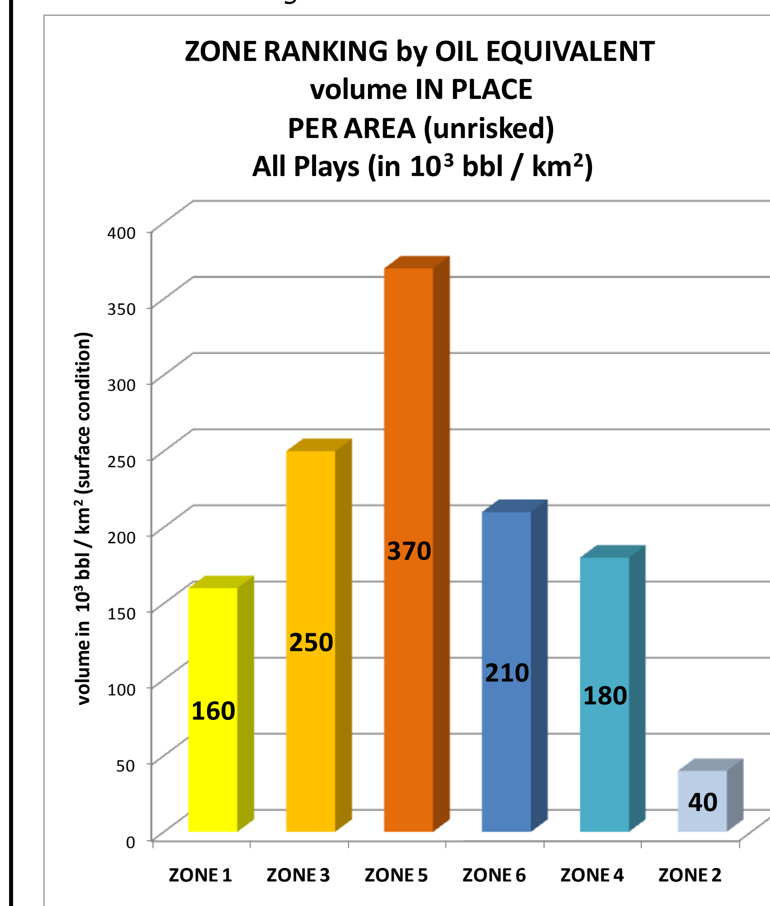
→ Geological context
→ Geological history
→ Deep geophysics
→ Geochemical data
→ Well log data
→ Petroleum field data

Temis 1D and 2D®

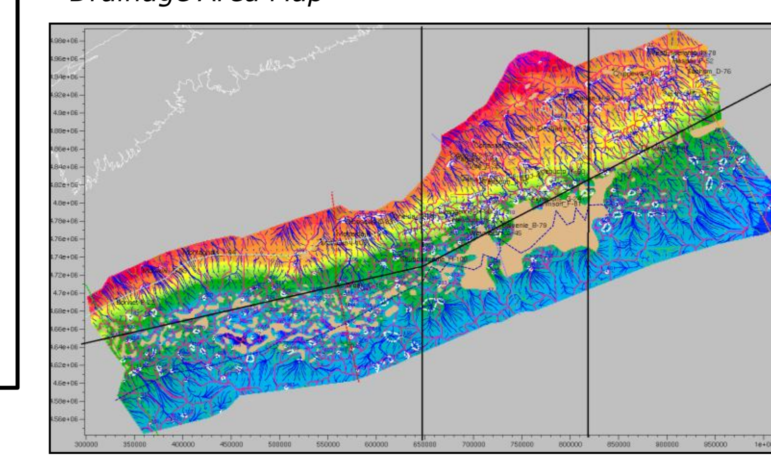
→ Preliminary evaluation of calibration data (petrophysical parameters, thermal boundaries)
→ Estimation of migration processes (full Darcy migration in 2D models)

2nd Modeling Phase

SubZone Ranking



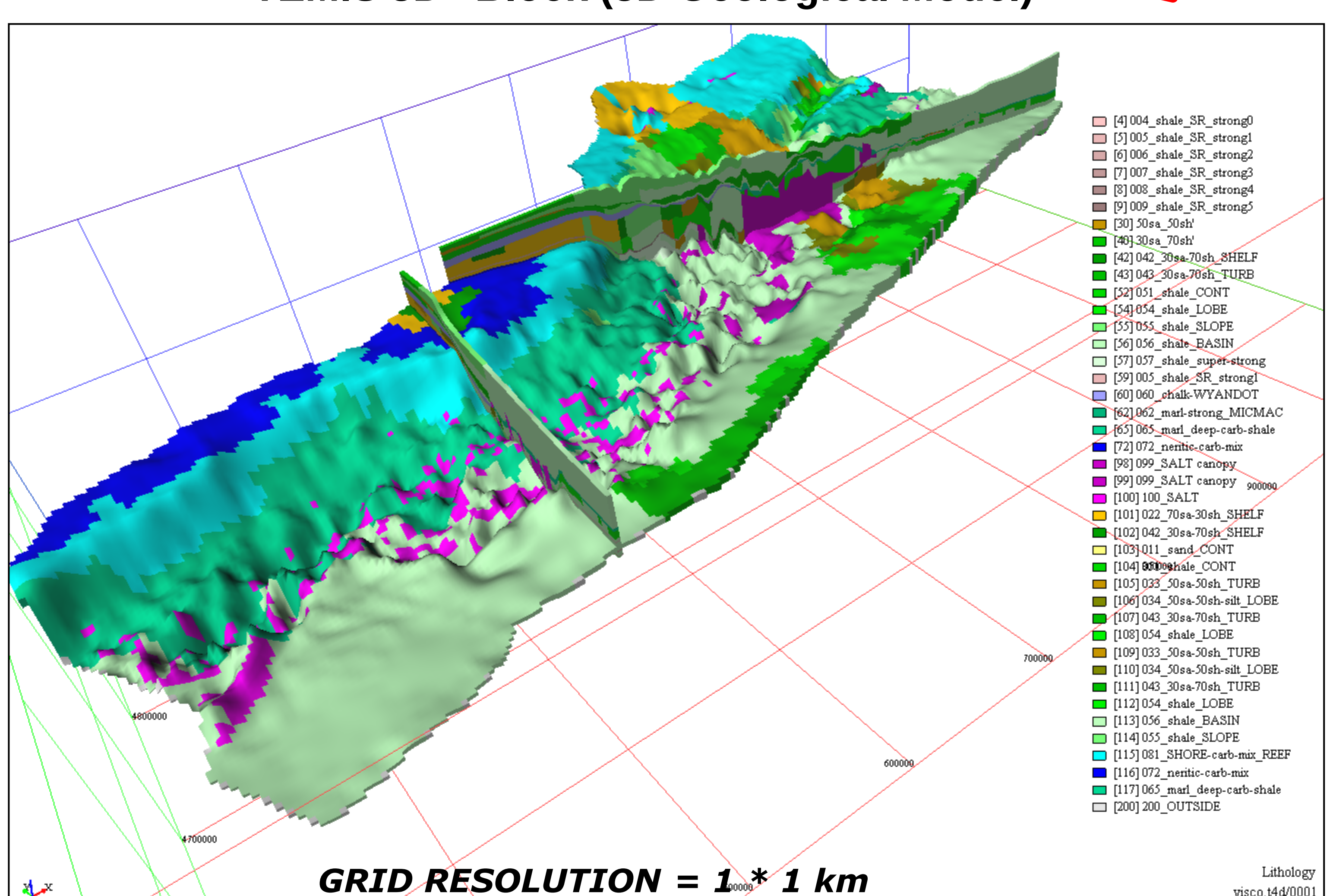
Drainage Area Map



Source Rocks Parameter
- Kerogens types
- Chemical kinetics
- TOC

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

TEMIS 3D® Block (3D Geological Model)



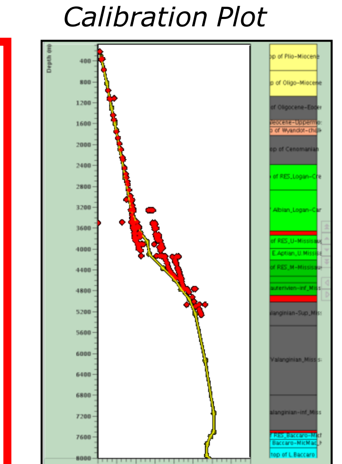
PRESSURE / TEMPERATURE / MATURITY MODELING

Calibration Phase
- Pressure
- Temperature
- Vitrinite

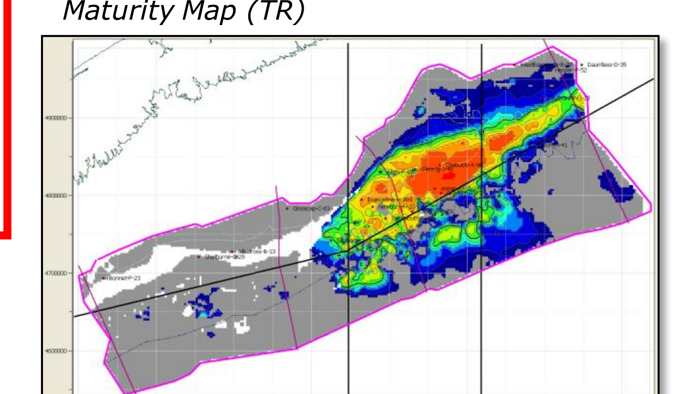
SR Modeling
- Present day maturity level
- Maturity history
- Expelled volumes

1st Modeling Phase

Calibration Plot



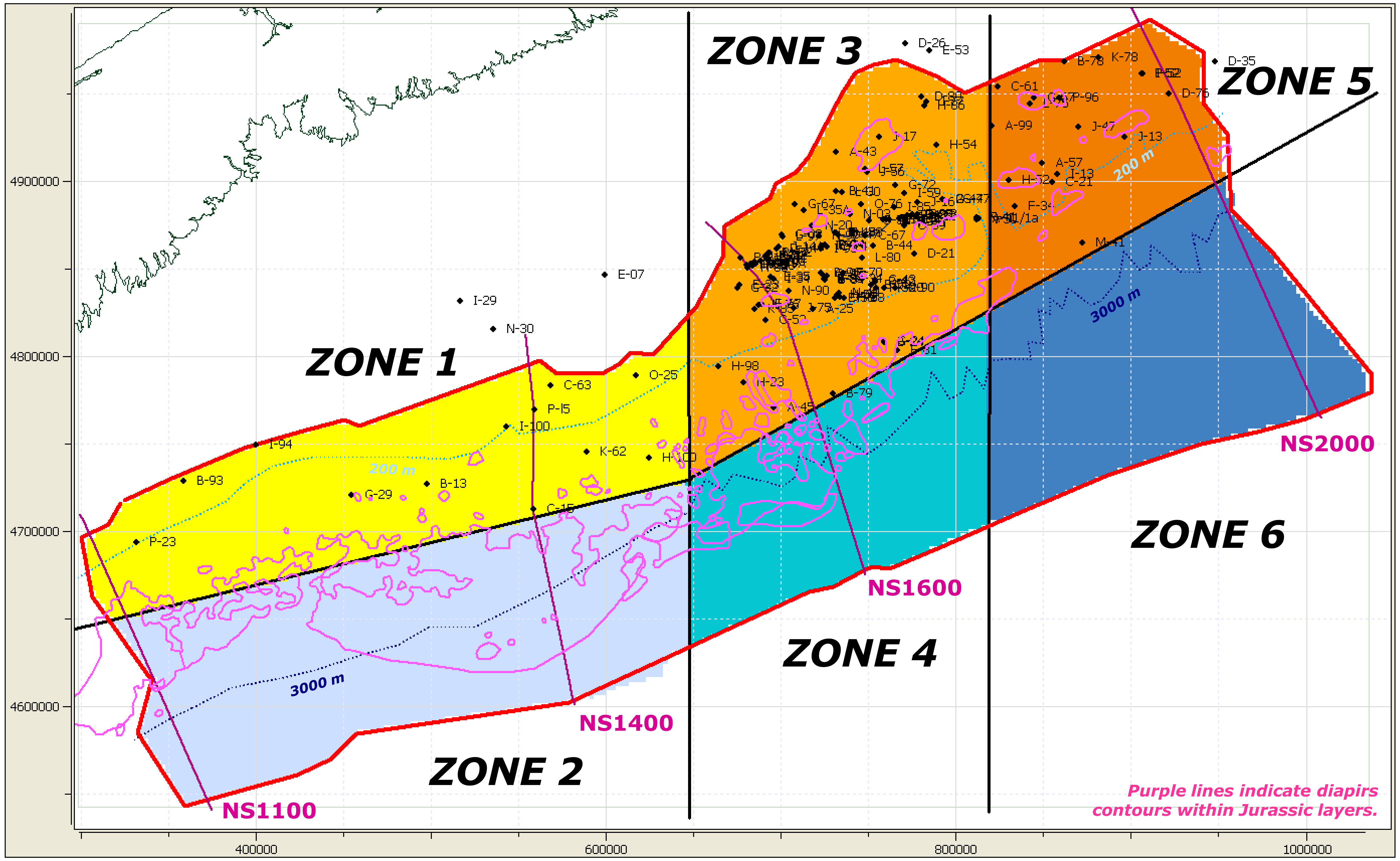
Maturity Map (TR)



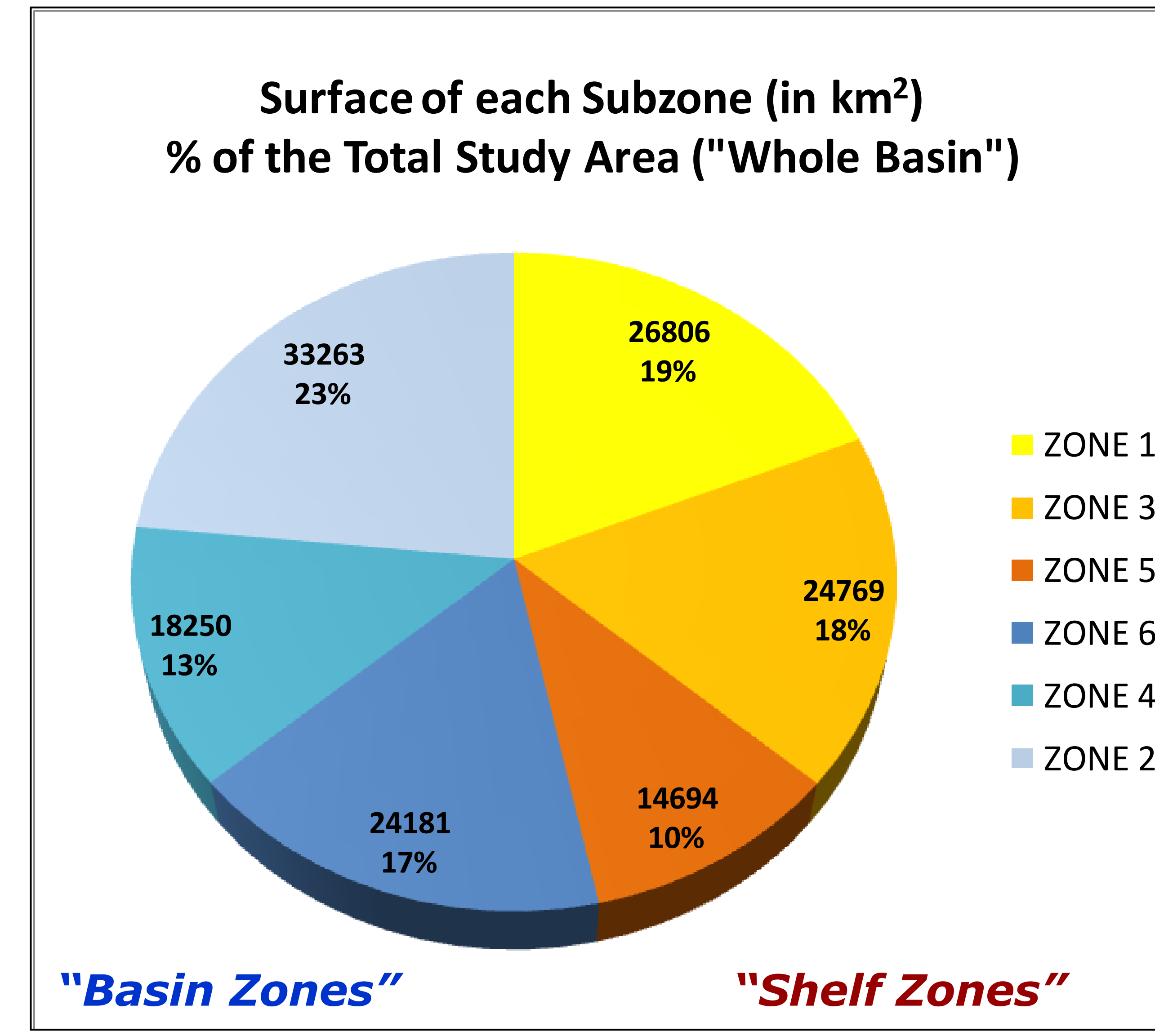
PLAY MODELING

Drainage Area Modeling
-Migration path in reservoir layers.
- Closed structures and porous volumes

HC Volume Estimations
- "Ray Tracing" Method (HC migration trough time between SRs and reservoirs)
- HC in place (mass, volume, composition)
- Unrisked results



By Zones	Number of cell in TEMIS 3D runs (each maps)	Surface (km2)
ZONE 1	4289	26806
ZONE 3	3963	24769
ZONE 5	2351	14694
ZONE 6	3869	24181
ZONE 4	2920	18250
ZONE 2	5322	33263
Whole Basin	**22714**	**141963**



All 3D Blocks are referenced in UTM coordinates (Zone 20, Northern Hemisphere).
The surface of the study area is close to 142000 km^2, about 42% of the total grid surface (as defined in PL. 7-3-1-1).

Notes on Subzone Definition

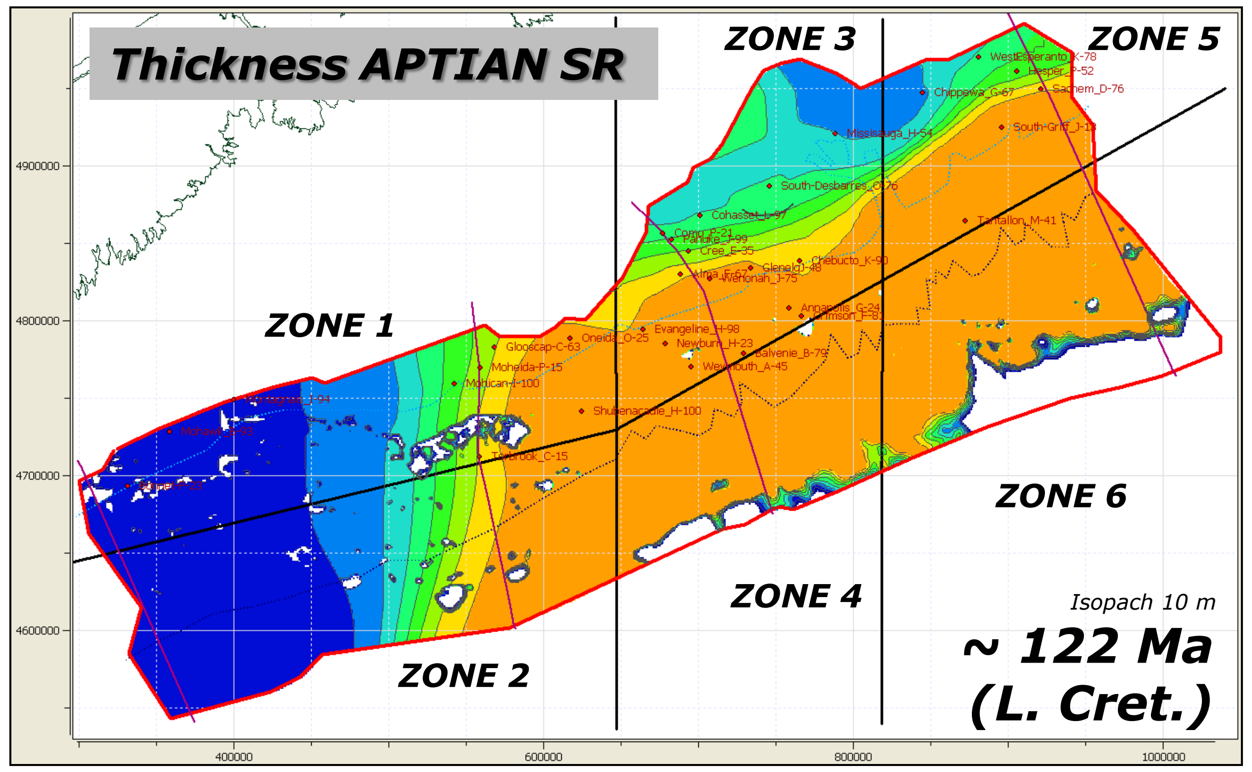
Several criteria have been used for Subzones definition:
- Distinction between "Basin" (also called "deep basin") and "Shelf" Zones. Limits between "Basin Zones" and "Shelf Zones" roughly correspond to isobath 2000 m.
- All drilled wells are in "Shelf Zones". "Basin Zones" are completely unexplored (no exploration well).
- The shape of the "salt basin" and structural style: Basin Zone 2 corresponds to the diapir area with isolated mini-basins; Basin Zone 4 corresponds to "canopy domain"; Basin Zone 6 is mainly covering the "Banquereau wedge" zone with reduced diapir activity except in the Northeasternmost part of the area where autochthonous salt induced diapirs.
- All the discoveries are in Zone 3 (Sable Sub Basin is included in Zone 3), except Banquereau (Zone 5).

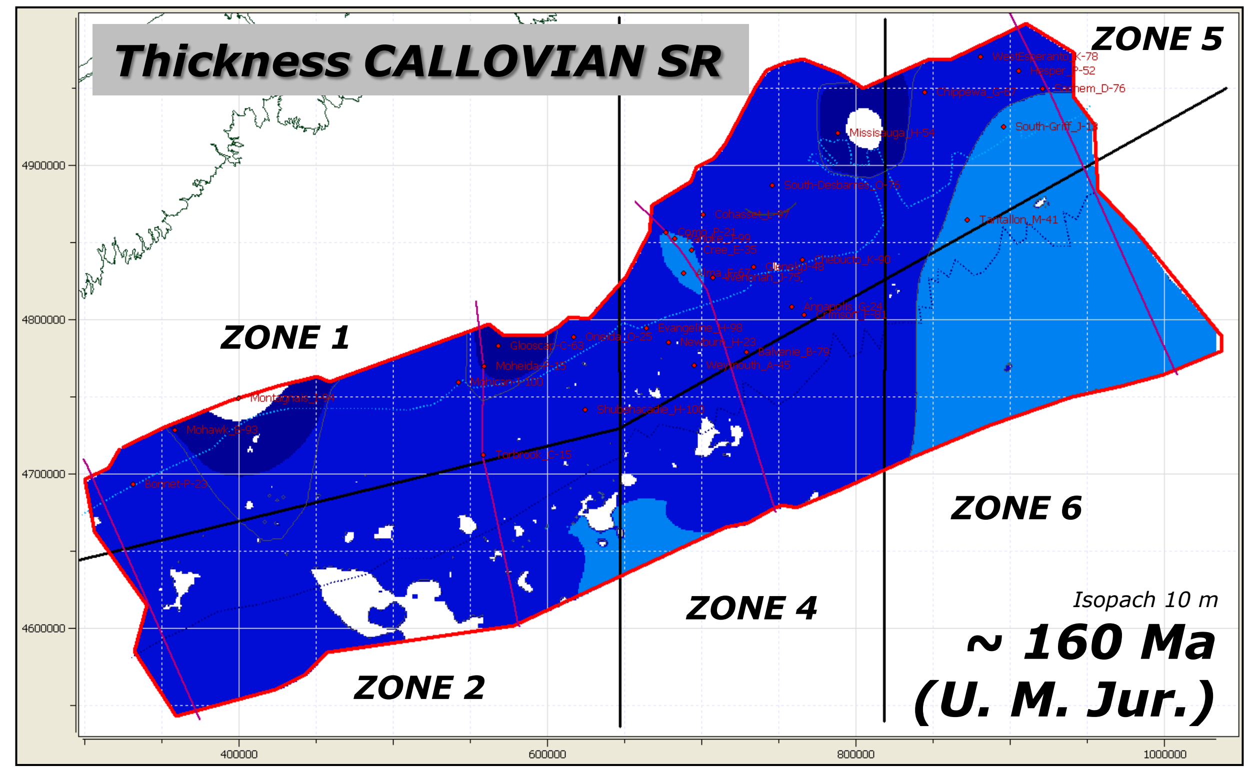
1	Quantitative / Well Constrained
2	
3	Semi Quantitative / Poorly Constrained
4	
5	Qualitative / Speculative

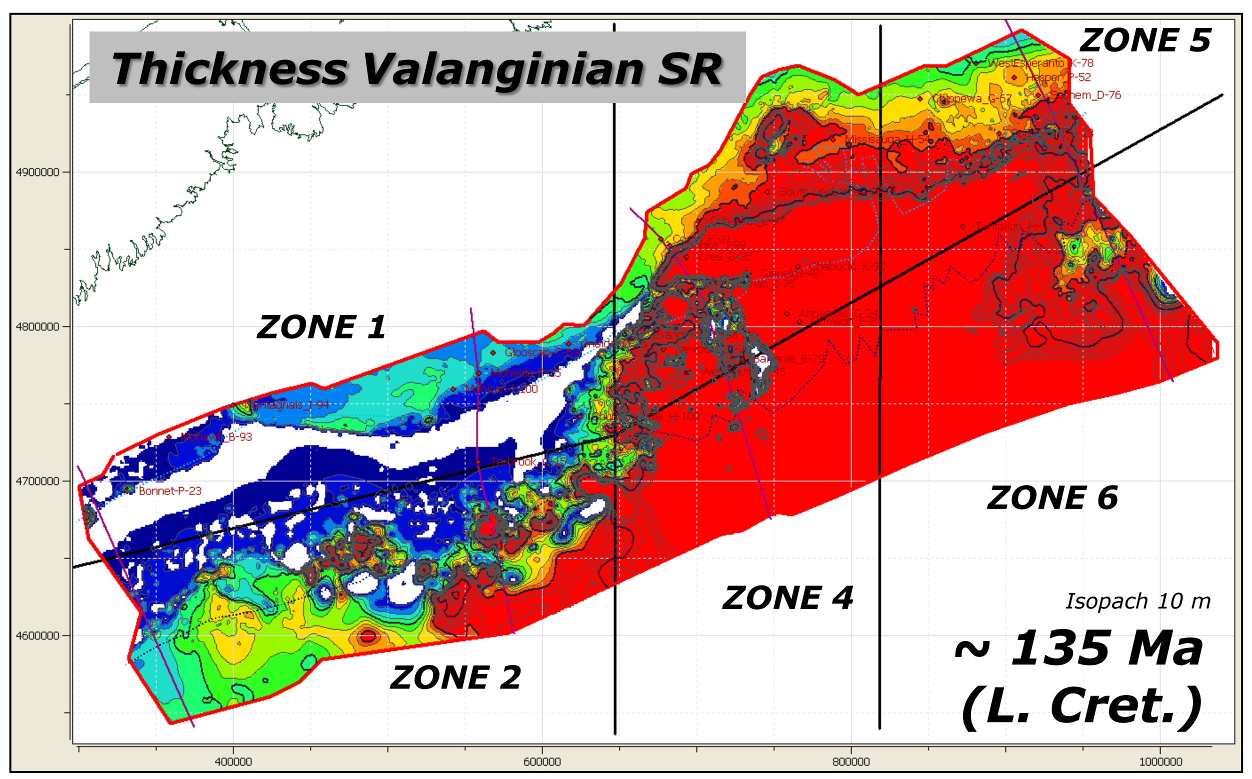
Modeling Result Confidence Chart

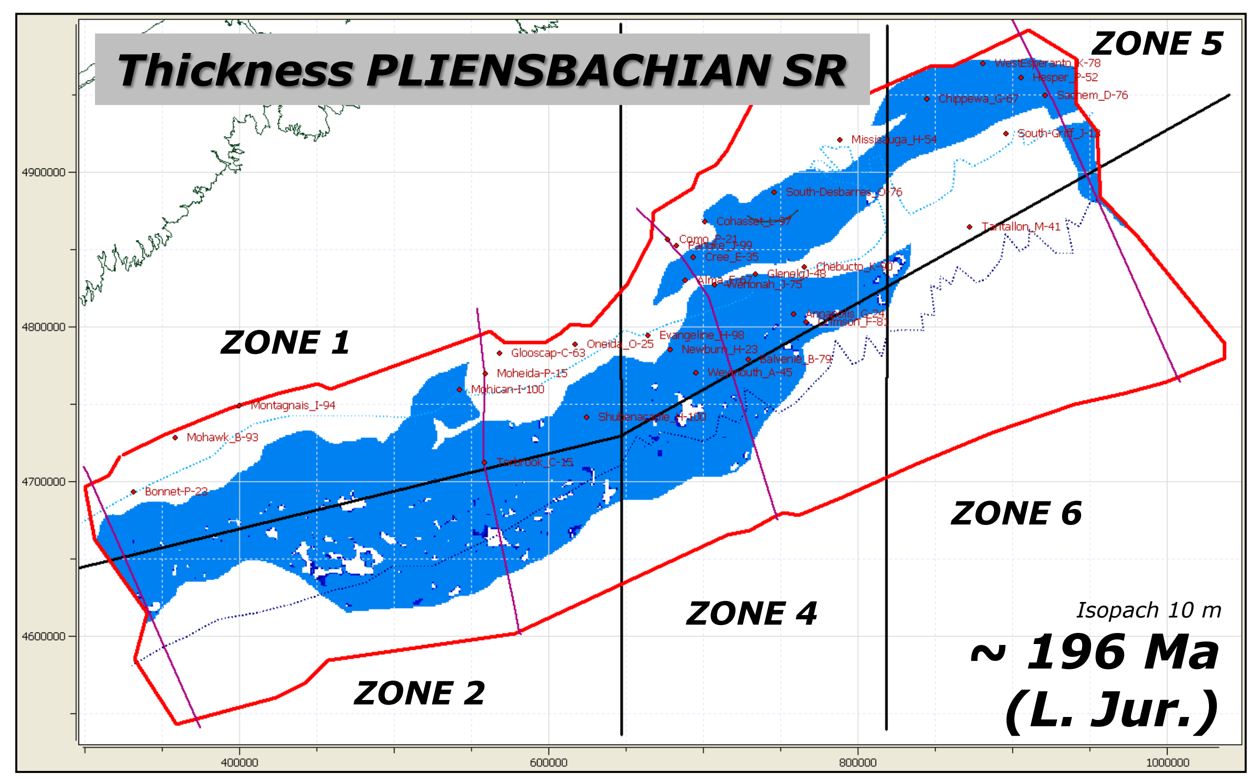
For main 3D modeling results, a "Modeling Result Confidence" is provided.
It corresponds to a value between 1 and 5 (1 → quantitative / well constrained result ; 5 → qualitative / speculative result).
The definition of this chart is empirical and can be used to compare uncertainties on different results, but does not give an absolute "uncertainty range" on each result.

It depends on:
-The position on the workflow (uncertainties are cumulated along the 3D modeling workflow, for example the definition of source rocks transformation ratio is better constrained than the definition of in place hydrocarbon volumes, which partly depends on the source rock maturity).
- The number of hypothesis necessary to obtain the result (for example the calculation of hydrocarbon volumes in surface conditions depends on an hypothesis on hydrocarbon densities, which induces a higher uncertainty on hydrocarbon volumes in comparison with hydrocarbon masses).









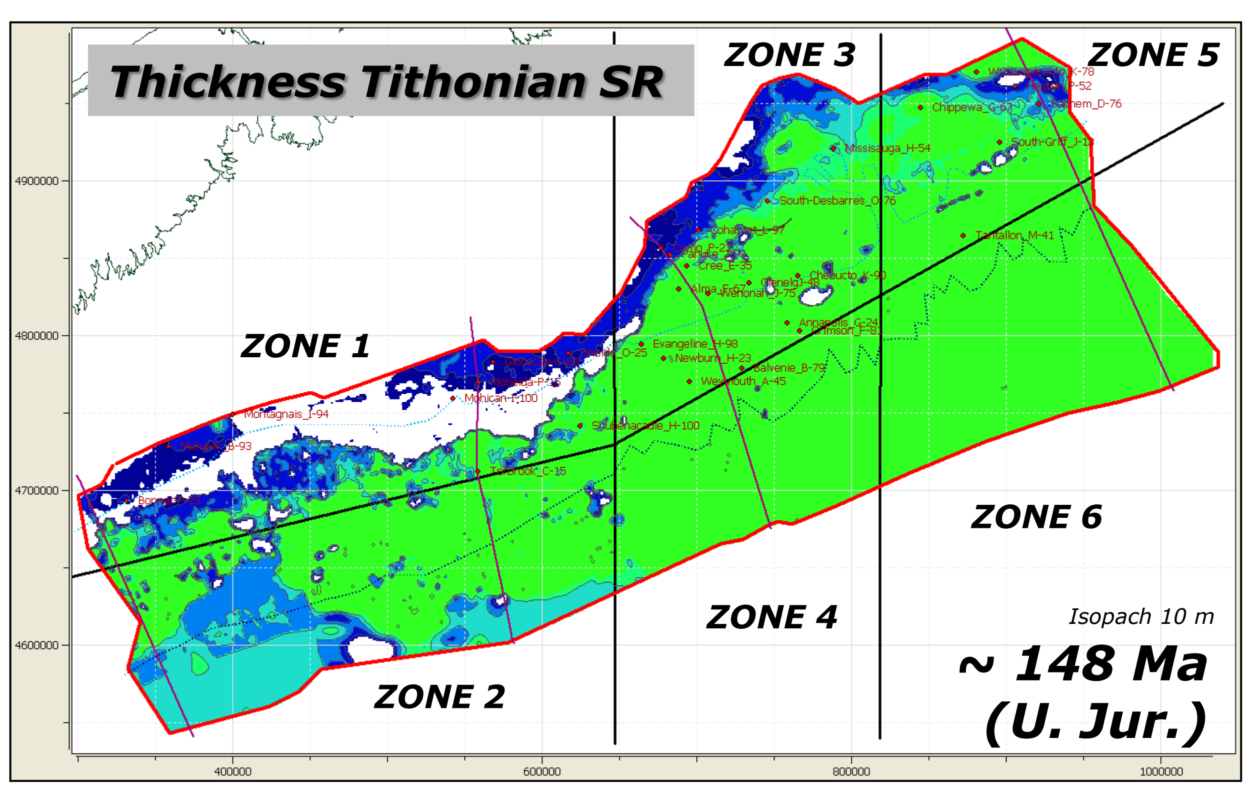
For each source rock, the "**Source Rock Thickness**" corresponds to the cumulated thicknesses of organic-rich intervals ("effective source rock thickness"). This thickness is estimated with well geochemical data (Rock Eval data) and structural data. It is extrapolated in "basin zones" (2; 4; 6). Thickness of the Pliensbachian SR is speculative.

As a consequence for each source rock a single organic-rich layer is considered in the 3D model.

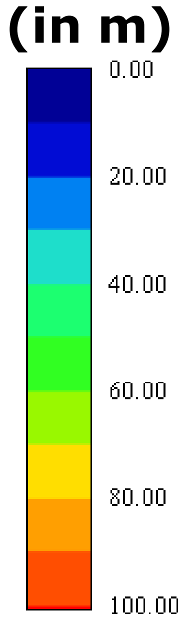
Source rocks petrophysical facies is defined as a specific shaly facies, and is assumed uniform.

The thickest source rocks are (by order):
- The Valanginian
- The Aptian
- The Tithonian
- The Pliensbachian
- The Callovian

See the table below for more details.



Source Rock Thickness (in m)



Source Rock	Approx. Age	Initial TOC	Kerogen type Initial HI	Description
APTIAN	122 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 – 100 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 – 200 m.
TITHONIAN	148 Ma	3 % (constant)	II-III mix HI = 424 mgHC/gTOC	Best defined SR, widely proven. Variable effective thickness between 0 – 50 m.
CALLOVIAN	160 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.
PLIENSBACHIAN (L. M. Jurassic)	196 Ma	5 % (constant)	II (marine) HI = 600 mgHC/gTOC (Toarcian. France) - Open system kinetics - Behar et al. 1997	Suspected, not proven. Potentially present above salt basins only. Assumed average thickness 20 m.

5 Source Rocks in the 3D Block.

Name	Color	Compound Type	Mobility	Preferred HC Phase	Thermal Stability
C1-C5		Hydrocarbon	Mobile	Vapor	Stable
C6-C13		Hydrocarbon	Mobile	Liquid	Unstable
C14+		Hydrocarbon	Mobile	Liquid	Unstable
Non-HC		Non Hydrocarbon	Mobile	Vapor	Stable
NSO-Oil		Hydrocarbon	Mobile	Liquid	Unstable
NSO-SR		Hydrocarbon	Immobile		Unstable
Precoke		Solid OM	Immobile		Unstable

Chemical Scheme

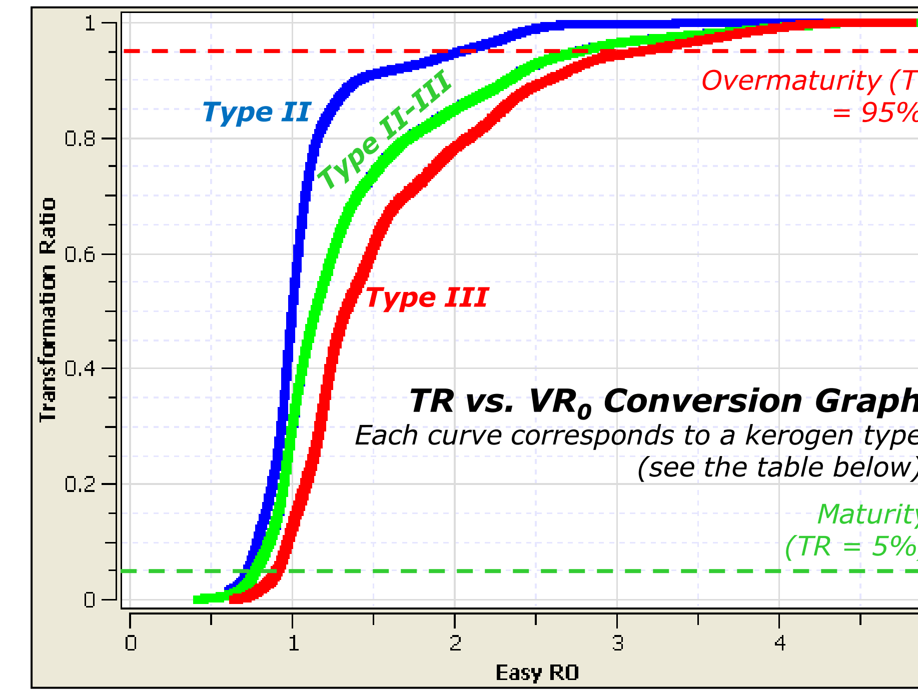
IFP 7 classes (+ coke) – 5 mobile fractions (Behar et al. 2008)

Maturation of initial kerogens can generate 8 families of chemical components.
All chemical "fractions" are not hydrocarbons, the "Non-HC" fraction mainly correspond to CO_2.
"C" refers to the number of carbon in aliphatic chains.
"NSO" refers to Nitrogen / Sulfur /Oxygen-rich molecules. This chemical fraction also contains heavy oils.
By definition {C1-C5} corresponds to the ***GAS***, {C6-C13 ; C14+ ; NSO-Oil} correspond to the ***OIL***.
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 (such as C14+) can be altered by secondary cracking. The secondary cracking generates lighter compounds (such as C6-C13) that can be cracked later in C1-C5 (witch is stable).

C1-C5	C6-C13	C14+	NSO-Heavy Oil
0.657 kg /m3	750 gk/m3	840 kg /m3	980 kg/m3

Average Densities at Surface Conditions (for the 3 mobile hydrocarbons classes)

Density are empirically defined for each fraction, and calibrated with API gravity observed in the Basin. The C1-C5 density (gas) is close to the methane density: methane 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% Maturity (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

Transformation Ratio vs. Vitrinite Reflectance

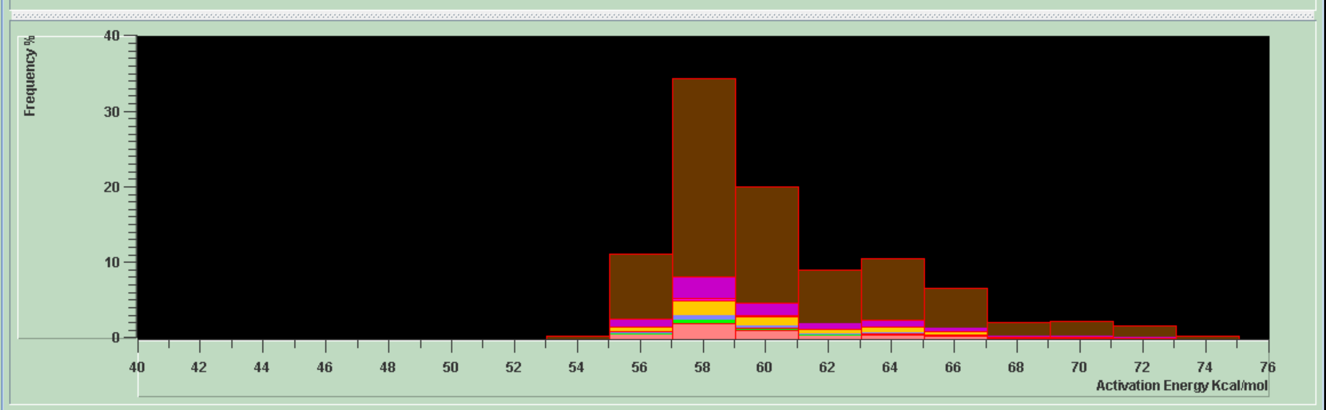
The Transformation Ratio (TR) corresponds to the fraction of initial kerogen that has been affected by maturation reactions. It is expressed in percent:

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 is an absolute maturity marker (not specific to a kerogen type).

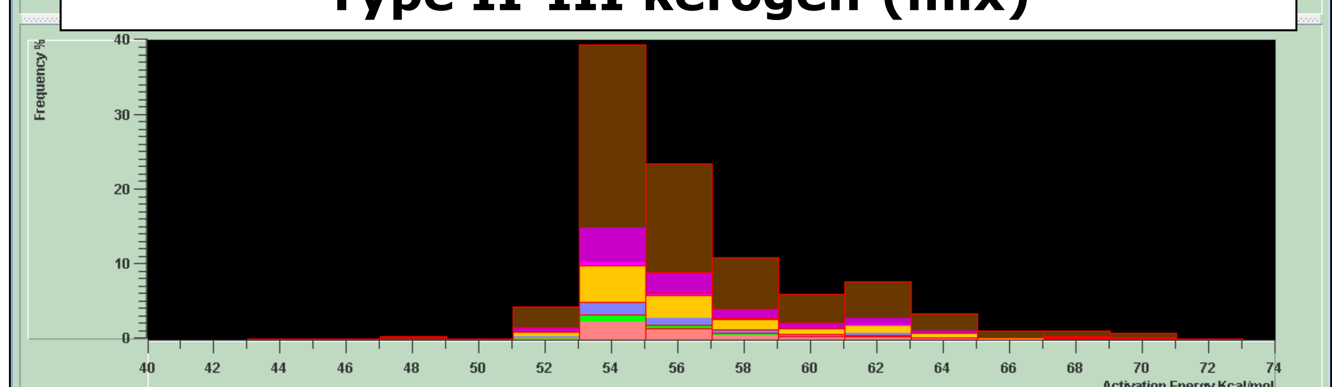
	Activation Energy Kcal/mol	Arrhenius Coefficient 1/s	Frequency %	Sums of Fractions %	C1-C5 %	C6-C13 %	C14+ %	Non-HC %	NSO-Oil %	NSO-SR %	Precoke %	Coke %
1	54.0	3.1E15	0.51	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
2	56.0	3.1E15	11.32	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
3	58.0	3.1E15	34.51	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
4	60.0	3.1E15	20.17	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
5	62.0	3.1E15	9.15	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
6	64.0	3.1E15	10.72	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
7	66.0	3.1E15	6.77	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
8	68.0	3.1E15	2.3	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
9	70.0	3.1E15	2.38	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
10	72.0	3.1E15	1.74	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0
11	74.0	3.1E15	0.43	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0

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



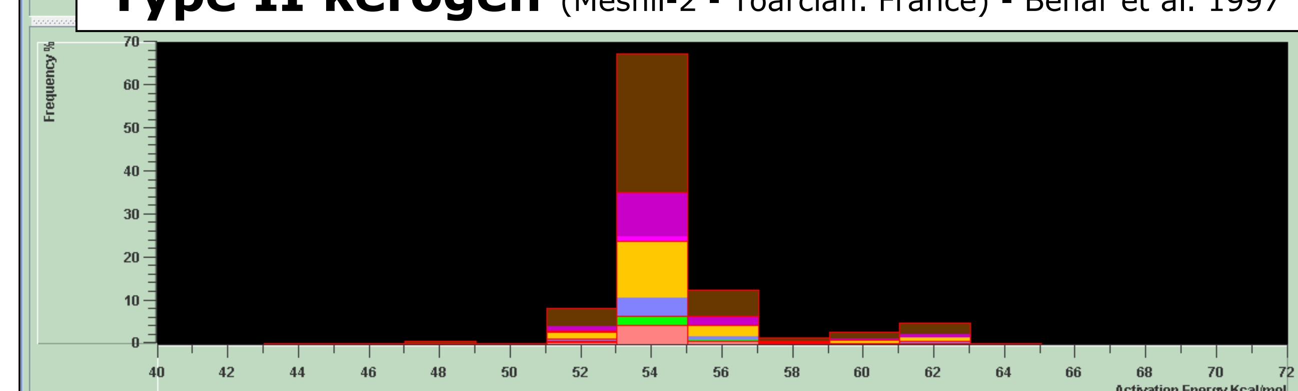
	Activation Energy Kcal/mol	Arrhenius Coefficient 1/s	Frequency %	Sums of Fractions %	C1-C5 %	C6-C13 %	C14+ %	Non-HC %	NSO-Oil %	NSO-SR %	Precoke %	Coke %
1	44.0	1.64E14	0.09	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
2	46.0	1.64E14	0.11	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
3	48.0	1.64E14	0.44	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
4	50.0	1.64E14	0.16	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
5	52.0	1.64E14	4.49	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
6	54.0	1.64E14	39.35	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
7	56.0	1.64E14	23.55	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
8	58.0	1.64E14	10.92	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
9	60.0	1.64E14	6.04	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
10	62.0	1.64E14	7.82	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
11	64.0	1.64E14	3.53	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
12	66.0	1.64E14	1.17	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
13	68.0	1.64E14	1.22	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
14	70.0	1.64E14	0.89	100.0	6.5	2.2	4.2	12.4	1.3	11.7	61.7	0.0
15	72.0	1.64E14	0.22	100.0	6.27	1.36	1.79	5.5	0.91	8.17	76.0	0.0

Type II-III kerogen (mix)



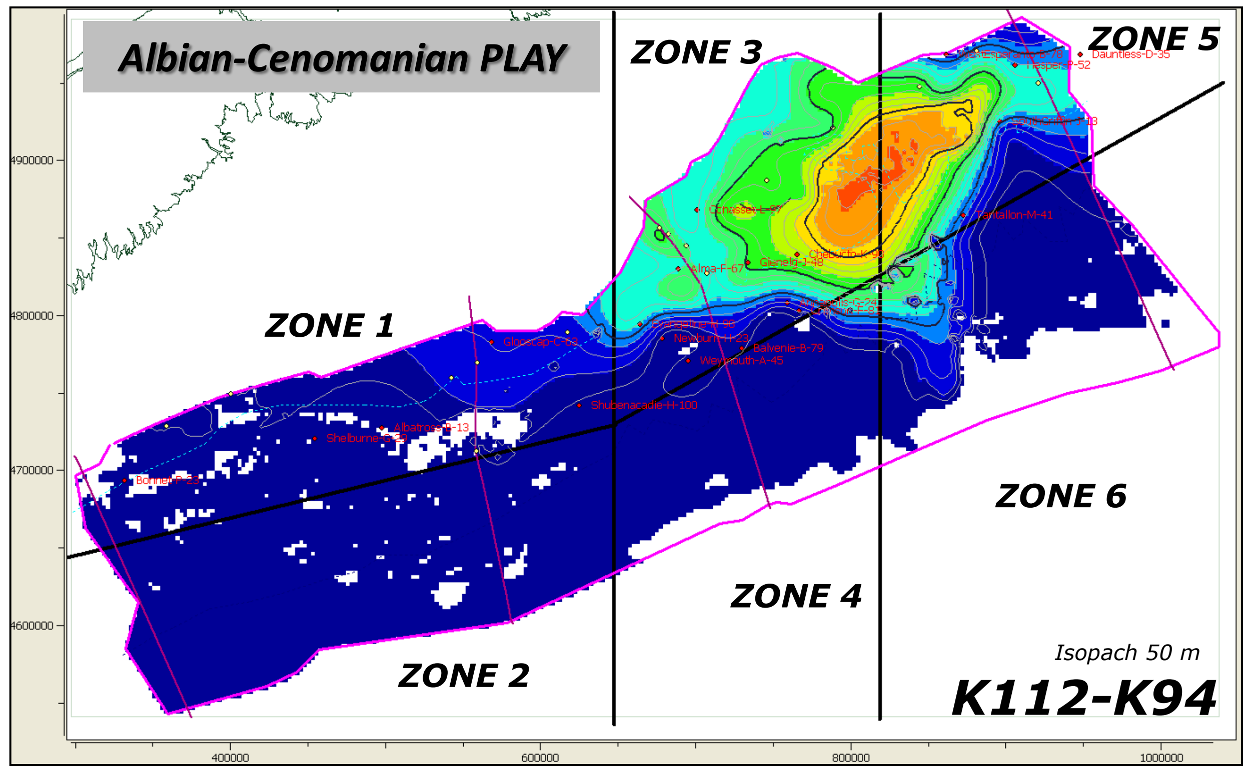
	Activation Energy Kcal/mol	Arrhenius Coefficient 1/s	Frequency %	Sums of Fractions %	C1-C5 %	C6-C13 %	C14+ %	Non-HC %	NSO-Oil %	NSO-SR %	Precoke %	Coke %
1	44.0	1.64E14	0.17	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
2	46.0	1.64E14	0.22	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
3	48.0	1.64E14	0.88	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
4	50.0	1.64E14	0.32	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
5	52.0	1.64E14	8.47	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
6	54.0	1.64E14	67.38	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
7	56.0	1.64E14	12.58	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
8	58.0	1.64E14	1.67	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
9	60.0	1.64E14	2.93	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
10	62.0	1.64E14	4.92	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
11	64.0	1.64E14	0.28	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
12	66.0	1.64E14	0.03	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
13	68.0	1.64E14	0.05	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0
14	70.0	1.64E14	0.1	100.0	6.72	3.08	6.55	19.3	1.68	15.17	47.5	0.0

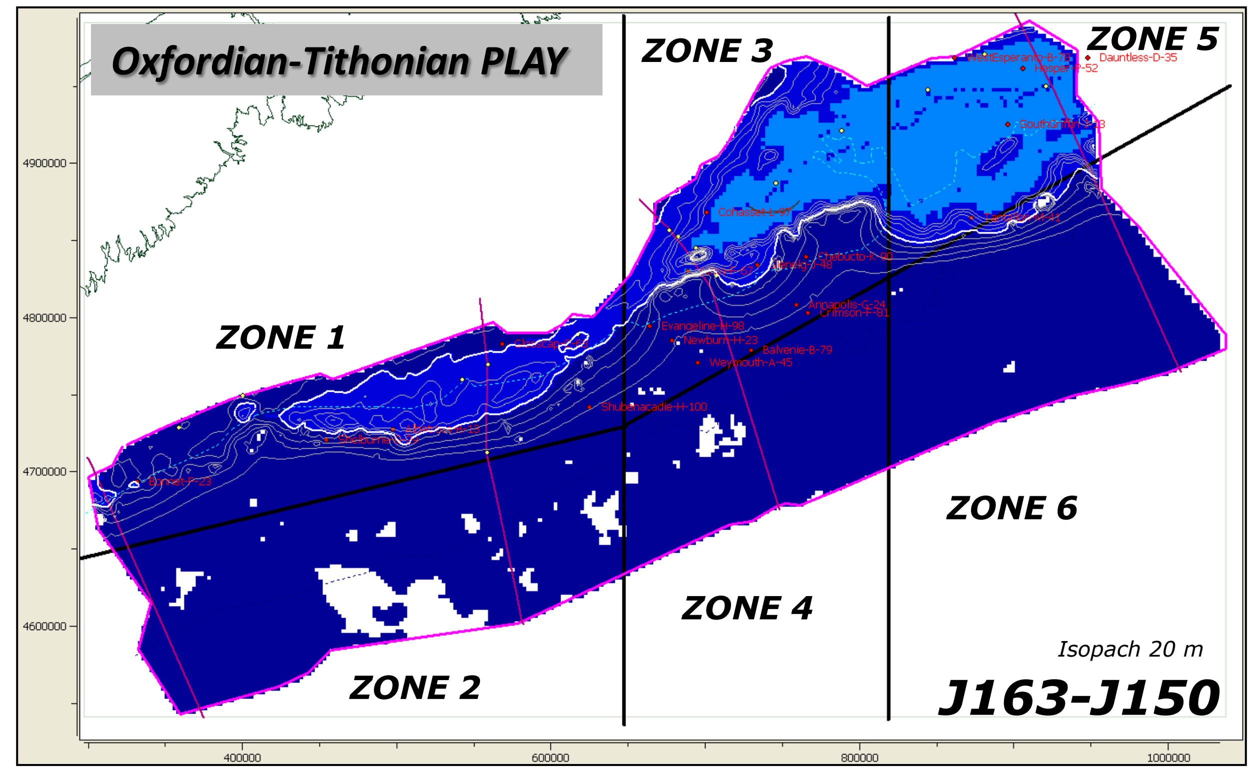
Type II kerogen (Mesnil-2 - Toarcian. France) - Behar et al. 1997

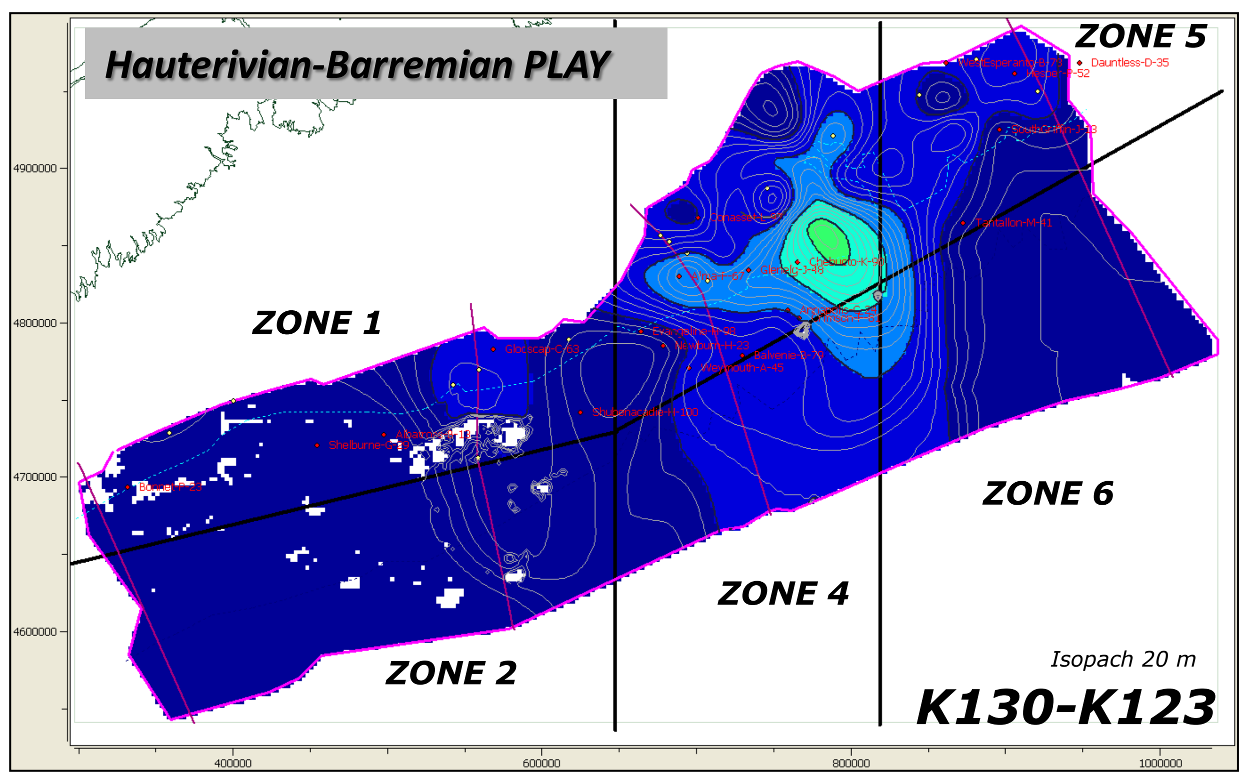


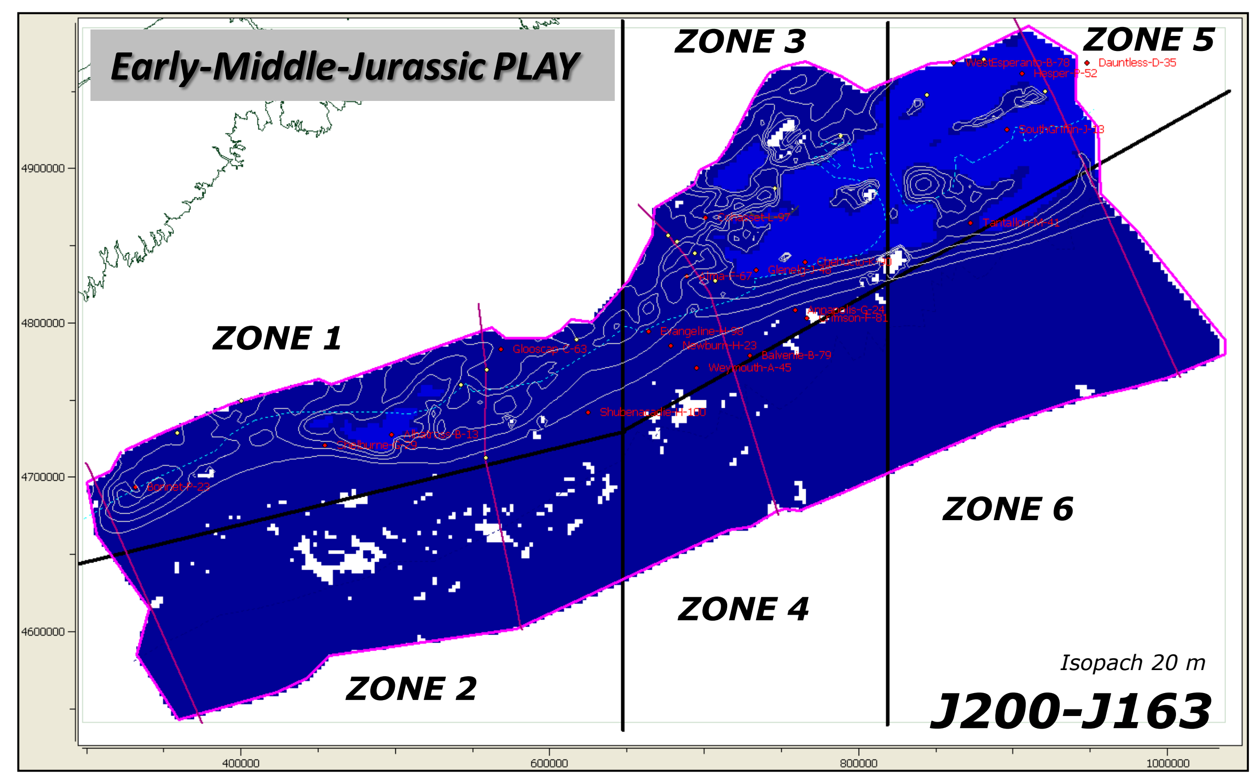
Kinetic Scheme

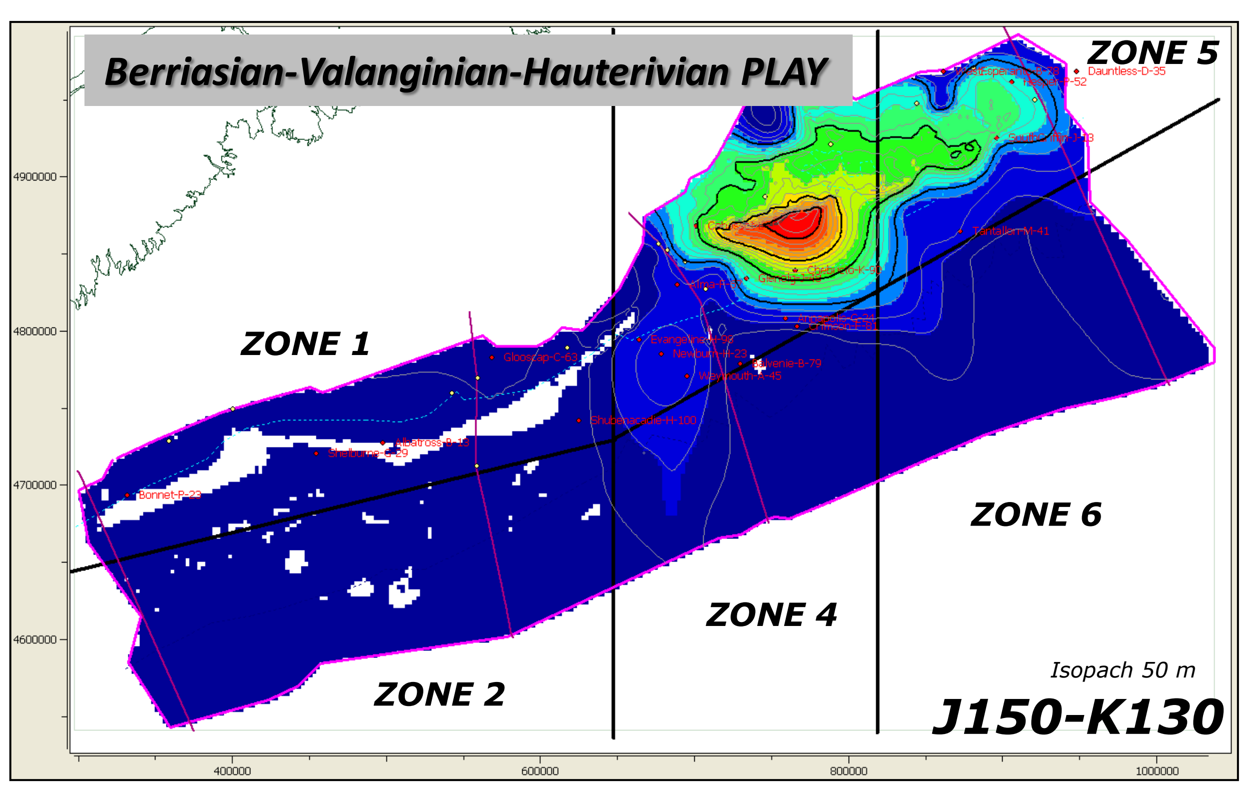
Kerogen maturation follows "kinetic schemes" specific to each kerogen type.
The maturation process is divided in "n" parallel chemical reactions (11 to 15 in that case) which have their own reaction speeds. Reaction speed is calculated with the Arrhenius Law and depends on: the Activation Energy, the Arrhenius Coefficient (specific to each chemical reaction), and the temperature. Each reaction generates chemical fractions defined by the chemical scheme.
Tables and graphs detail the 3 kinetic schemes used in this study (Type III, Type II-III, Type II). These schemes come from the Temis Default Library (specific data not available for Nova Scotia).
Secondary cracking reactions follow the same kind of kinetics laws.

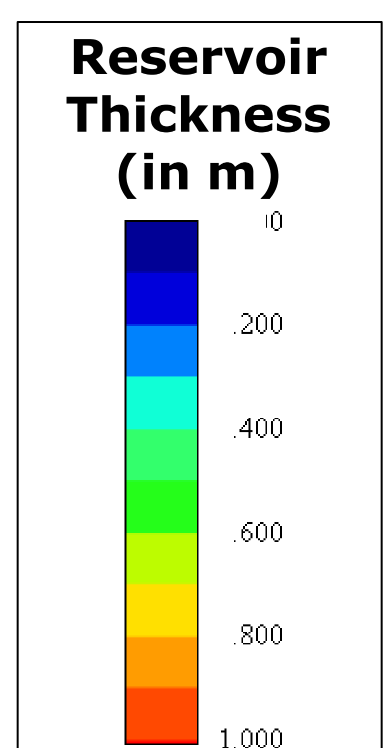












For each **"play system"**, a **"virtual" reservoir layer** is implemented in the 3D model. Hydrocarbon volumes and characteristics are computed in this layer.

"**Reservoir Thicknesses**" correspond to "**Net Thicknesses**" in the sedimentary sequences corresponding to play intervals, that is to say cumulated thicknesses of porous intervals. This "Net thickness" is estimated with well log data and extrapolated with Dionisos® in "basin zones" (2; 4; 6). Thicknesses of "Oxfordian-Tithonian" and "Early-Middle-Jurassic" play systems are speculative.

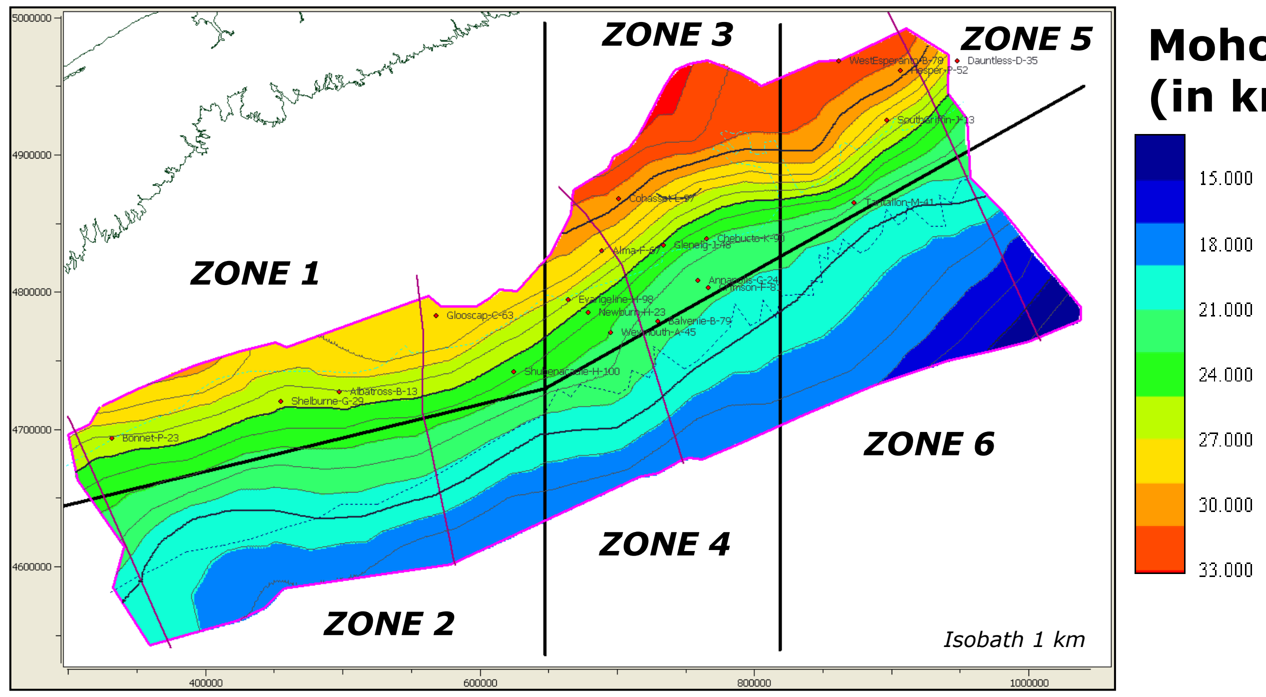
"Real" reservoir layers may be scattered in the sedimentary sequence corresponding to the play interval, particularly if the "net to gross" is low (clay >>> sand). These "virtual reservoirs" are arbitrarily located at the upper part of play intervals (see the stratigraphic chart, PL. 7-3-1-1).

Reservoir rocks petrophysical facies are defined as specific sandy facies (Cretaceous Plays), or special sandy / carbonaceous facies (Jurassic Plays). The distribution is not uniform: Sediment grain size is considered coarser on the shelf than in the deep water basin. Moreover a distinction is done in the Oxfordian-Tithonian Play between "Baccaro-type" (Zone 1 and part of Zone 3), "Mic Mac-type" (Zone 5 and part of Zone 3), and "intermediary-type" reservoirs (Zone 3).

Reservoirs are the thicker in Zone 3 and Zone 5, on the shelf.

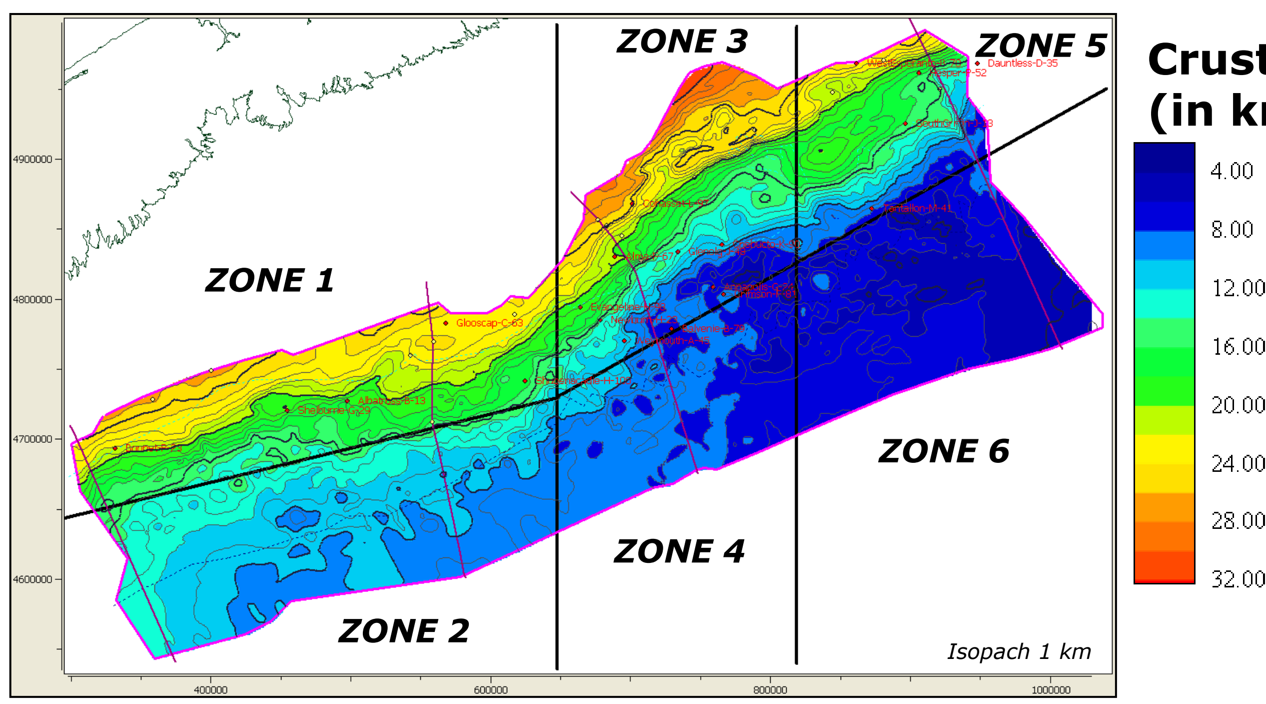
Reservoir Sequence	Age Interval	Petrophysical Facies	Depth(m) Range	Porosity(/) Range	Description
Aptian-Albian-Cenomanian	112-94 Ma	-Sandstone on the Platform -Sand and Silt Mixed Lithology in the Slope and Basin areas	-On the Platform Depth[1000;4000] -Slope and Basin areas Depth[3000;7000]	-On the Platform Porosity [0.12; 0.35] -Slope and Basin areas Porosity [0.05; 0.15]	In the northeastern part of the Basin this sequence contains the Logan and Cree formations.
Hauterivian-Barremian	130-123 Ma	-Sandstone on the Platform -Sand and Silt Mixed Lithology in the Slope and Basin areas	-On the Platform Depth[1200;5000] -Slope and Basin areas Depth[4000;7000]	-On the Platform Porosity [0.10; 0.32] -Slope and Basin areas Porosity [0.03; 0.13]	In the northeastern part of the Basin this sequence contains the Upper Mississauga formation.
Berriasian-Valanginian-Hauterivian	150-130 Ma	-Sandstone on the Platform -Sand and Silt Mixed Lithology in the Slope and Basin areas	-On the Platform Depth[1200;6000] -Slope and Basin areas Depth[4000;8000]	-On the Platform Porosity [0.14; 0.35] -Slope and Basin areas Porosity [0.03; 0.12]	In the northeastern part of the Basin this sequence contains the Lower and Middle Mississauga formations.
Oxfordian-Tithonian	163-150 Ma	-East of Platform: Sandstone -West of Platform: Carbonates (Lagoon, Nearshore, Detritic) -Sand and Silt Mixed Lithology in the Slope and Basin areas	-East of Platform Depth[2000;5000] -West of Platform Depth[1200;8000] -Slope and Basin areas Depth[4000;12000]	-East of Platform Porosity [0.10; 0.27] -West of Platform Porosity [0.03; 0.20] -Slope and Basin areas Porosity [0.02; 0.07]	In the northeastern part of the Basin this sequence contains the Mic Mac formation, and in the northwestern part of the basin it contains the Baccaro formation.
Early-Middle-Jurassic	200-163 Ma	- Lagoon Carbonate on the Platform - Sand and Silt Mixed Lithology in the Slope and Basin areas	-On the Platform Depth[2000;9000] -Slope and Basin areas Depth[4000;13000]	-On the Platform Porosity [0.02; 0.09] -Slope and Basin areas Porosity [0.01; 0.07]	In the northwestern part of the basin this sequence contains the Scatarie formation.

5 Reservoir Layers in the 3D Block.



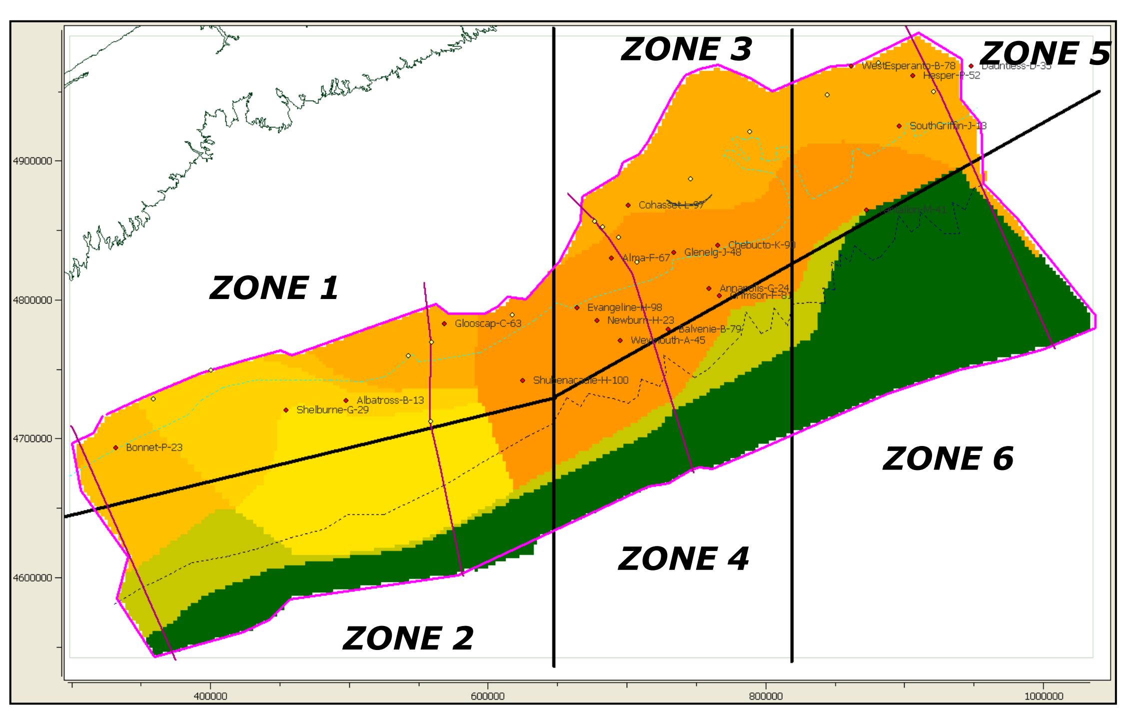
Moho Depth (in km)

The Moho depth varies between 14 and 33 km in the study Area. It reaches 42 km below New Found Land. (After Dr. S. Dehler from the GSC)

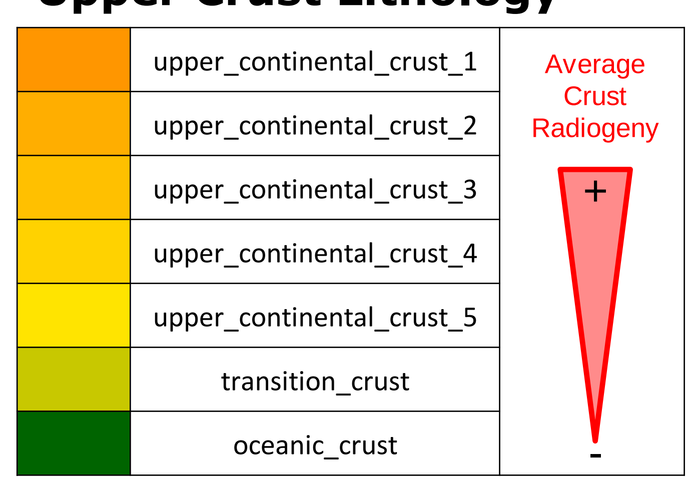


Crust Thickness (in km)

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



Upper Crust Lithology



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 is estimated with:
- Geophysical data for oceanic crust (estimated rock densities) and transition crust (seaward dipping reflectors);
- Thermal calibration with well data.

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)

BASEMENT STRUCTURE

Basement structure has a strong impact on thermal modeling due to:
- The rifting at the beginning of the modeling (about 225 → 200 Ma);
- The disintegration of radiogenic elements in the crust;
- The better constraint on the "Blancketing Effect" due to high sedimentation rates.

Before Rifting (225 Ma)

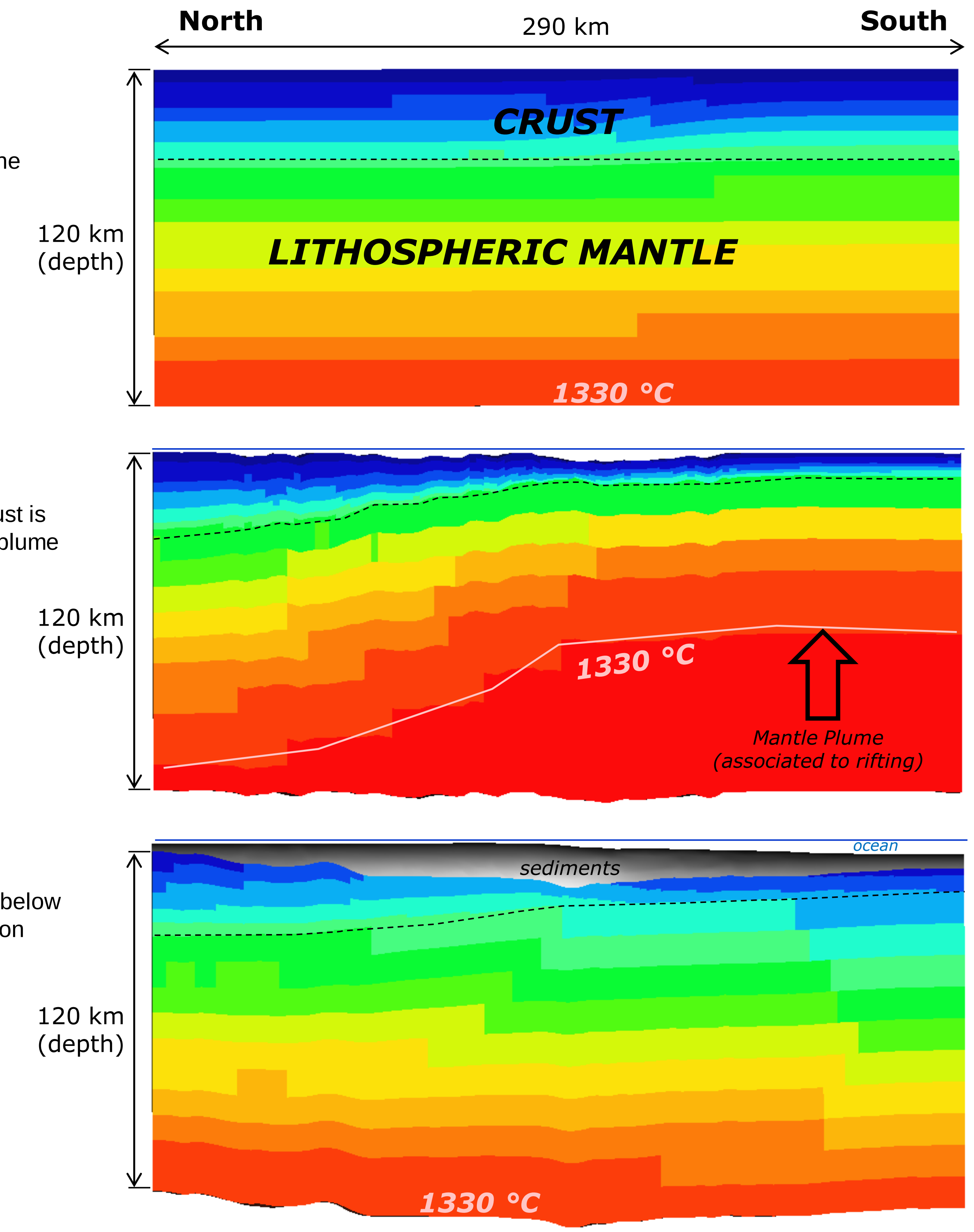
Relatively uniform temperature field.
1330°C at the base of the lithosphere (base of the model)

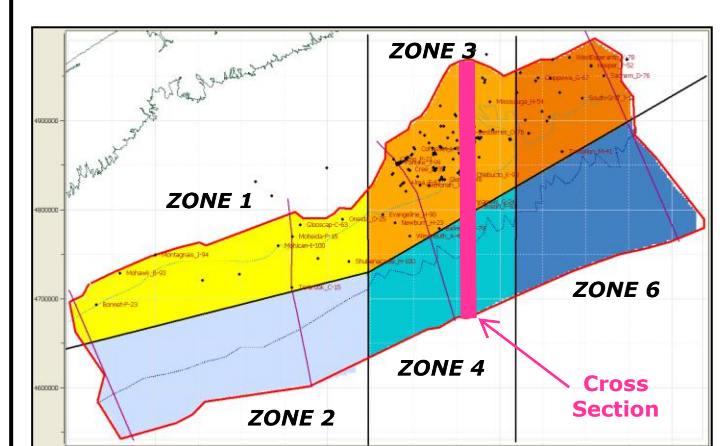
After Rifting (196 Ma)

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

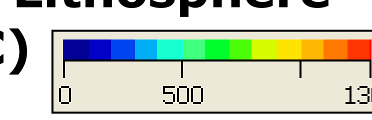
Present Day (0 Ma)

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





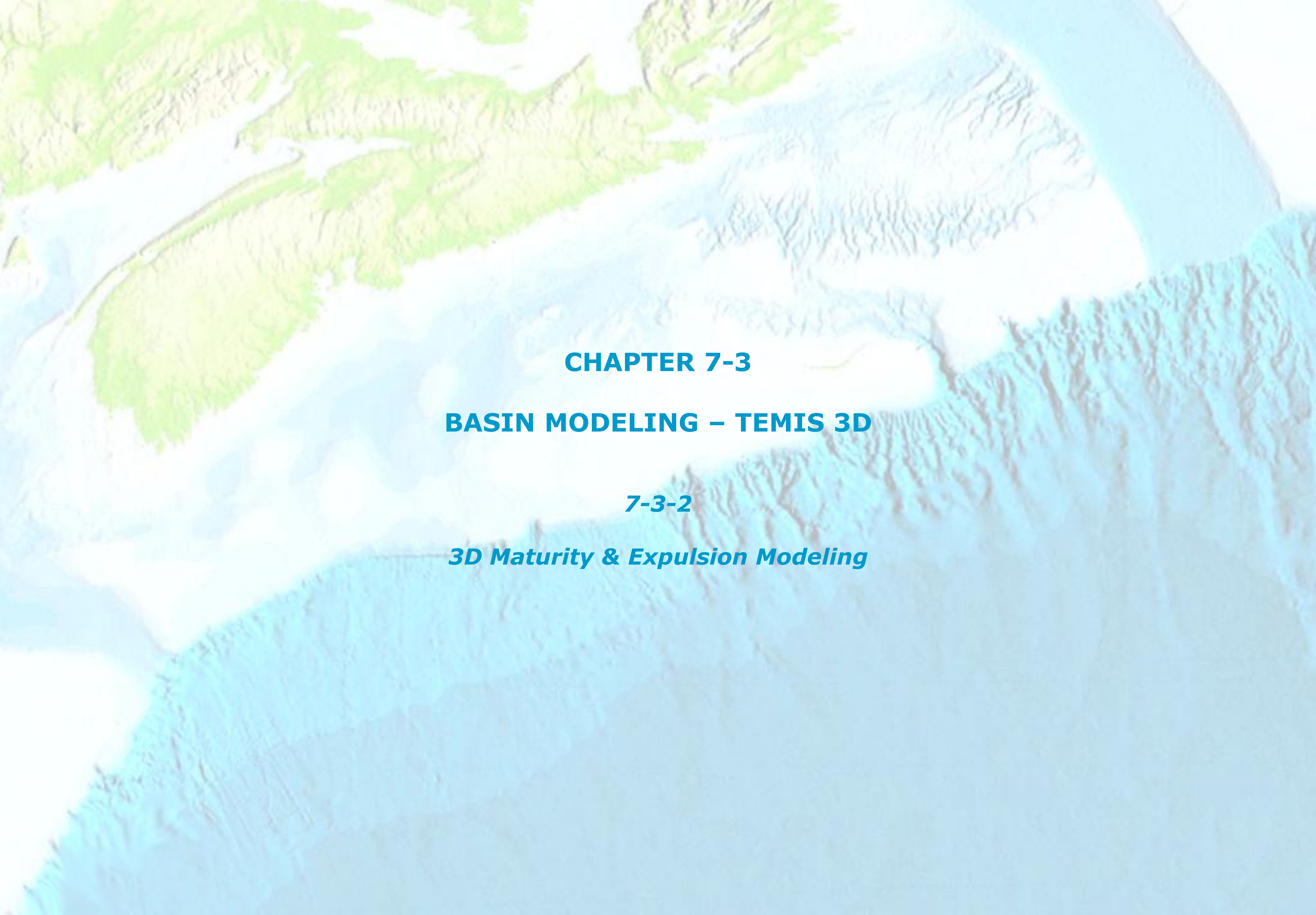
CROSS SECTION –RIFTING HISTORY Temperature in the Lithosphere at 3 key ages (in °C)



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.

Age	Average surface Temperature
0 Ma (present day)	Variable with the depth average = 6.2°C
29 Ma	average = 13.5°C
50 Ma	average = 24°C
94 Ma	average = 25°C
150 Ma	average = 26°C



CHAPTER 7-3

BASIN MODELING – TEMIS 3D

7-3-2

3D Maturity & Expulsion Modeling

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

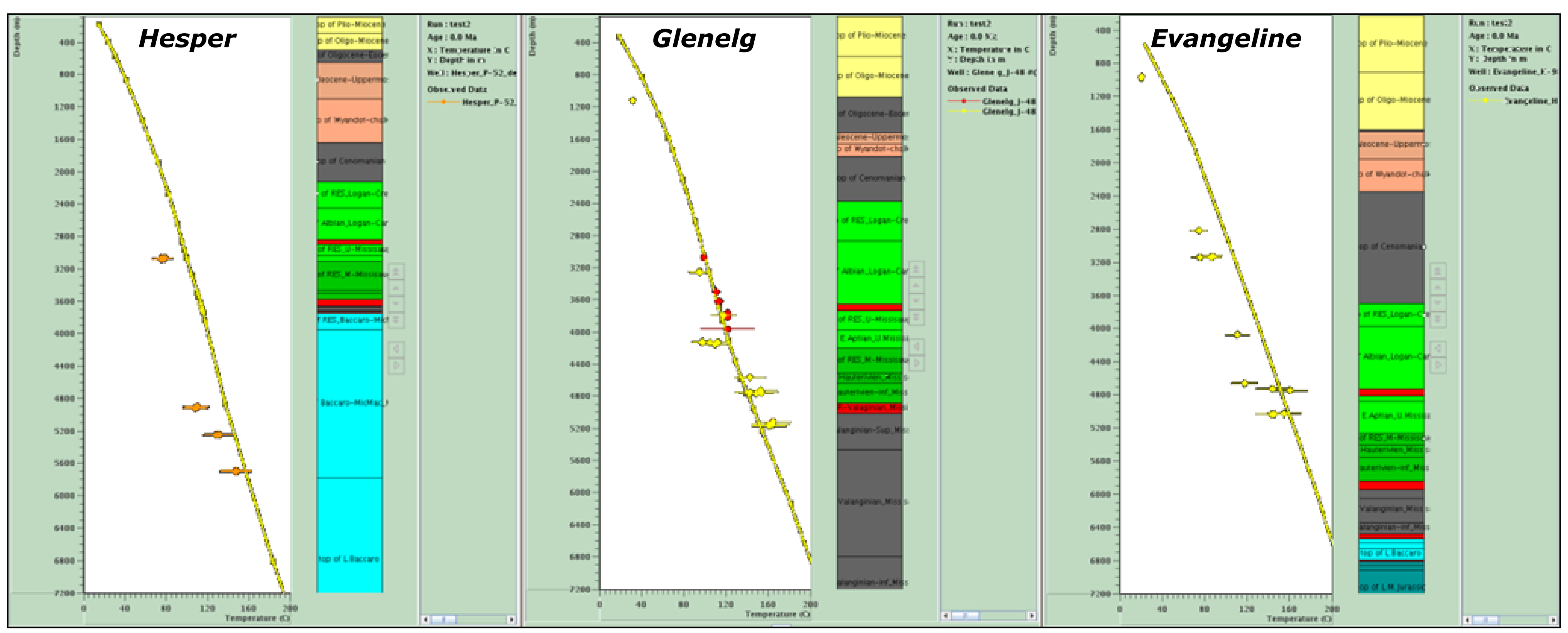
The evolution of the whole 3D block (geological model) is simulated through geological times:

→ 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)

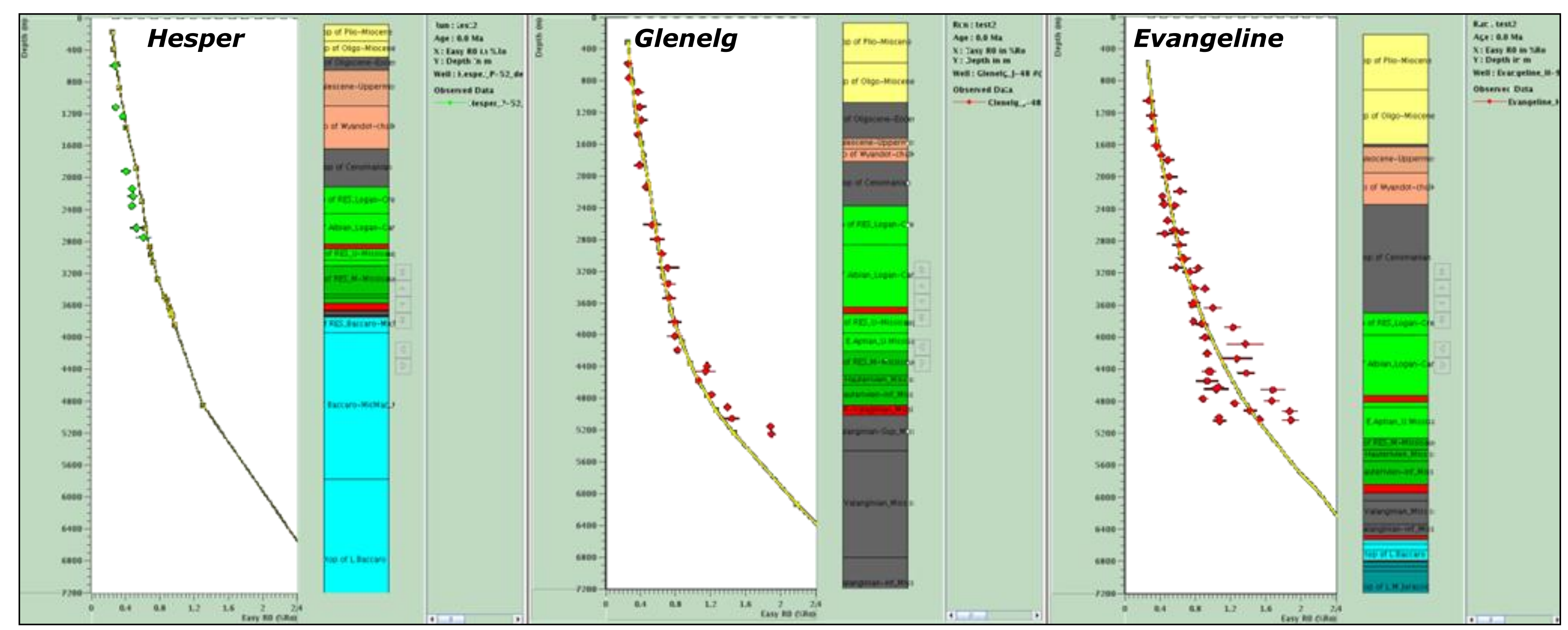
Results will be used for the migration and reservoir modeling, and later for the definition of some CRS maps (maturity maps, porosity maps, etc.).

Calibration Wells	X (UTM 20)	Y (UTM 20)	Temperature Data	Maturity Data	Pressure Data	Zone
Alma_F-67	688396	4830450	X	X	X	Zone 3
Annapolis_G-24	758530	4808827	X	X	X	Zone 3
Balvenie_B-79	729167	4779300		X	X	Zone 3
Bonnet-P-23	331187	4693811	X	X	X	Zone 1
Chebucto_K-90	764931	4839413	X		X	Zone 3
Chippewa_G-67	844221	4948092	X		X	Zone 5
Cohasset_L-97	700665	4868439	X	X	X	Zone 3
Como_P-21	676415	4856902	X		X	Zone 3
Cree_E-35	693360	4845483	X		X	Zone 3
Crimson_F-81	766218	4803555	X		X	Zone 3
Evangeline_H-98	663817	4794872	X	X	X	Zone 3
Glenelg_J-48	733410	4834340	X	X	X	Zone 3
Glooscap-C-63	567776	4783451	X	X		Zone 1
Hesper_P-52	905676	4961896	X	X	X	Zone 5
Missisauga_H-54	788350	4921239	X		X	Zone 3
Mohawk_B-93	358182	4729064	X		X	Zone 1
Moheida-P-15	558692	4769993	X	X	X	Zone 1
Mohican-I-100	542314	4760084	X	X	X	Zone 1
Montagnais_I-94	399604	4749634	X		X	Zone 1
Newburn_H-23	678253	4785654	X	X	X	Zone 3
Oneida_O-25	616890	4789287	X			Zone 1
Panuke_J-99	682308	4853180	X			Zone 3
Sachem_D-76	920778	4950416	X		X	Zone 5
Shubenacadie_H-100	624367	4742241	X	X	X	Zone 1
South-Desbarres_O-76	745491	4887217	X		X	Zone 3
South-Griffith_J13	895805	4925565	X	X	X	Zone 5
Tantallon_M-41	871898	4865286	X	X	X	Zone 5
Torbrook_C-15	558012	4712804	X	X	X	Zone 1
Wenonah_J-75	706941	4827784	X		X	Zone 3
West-Esperanto_K-78	880590	4970901	X	X	X	Zone 5
Weymouth_A-45	695037	4770821	X		X	Zone 3

List of the 31 calibration wells



TEMPERATURE Calibration

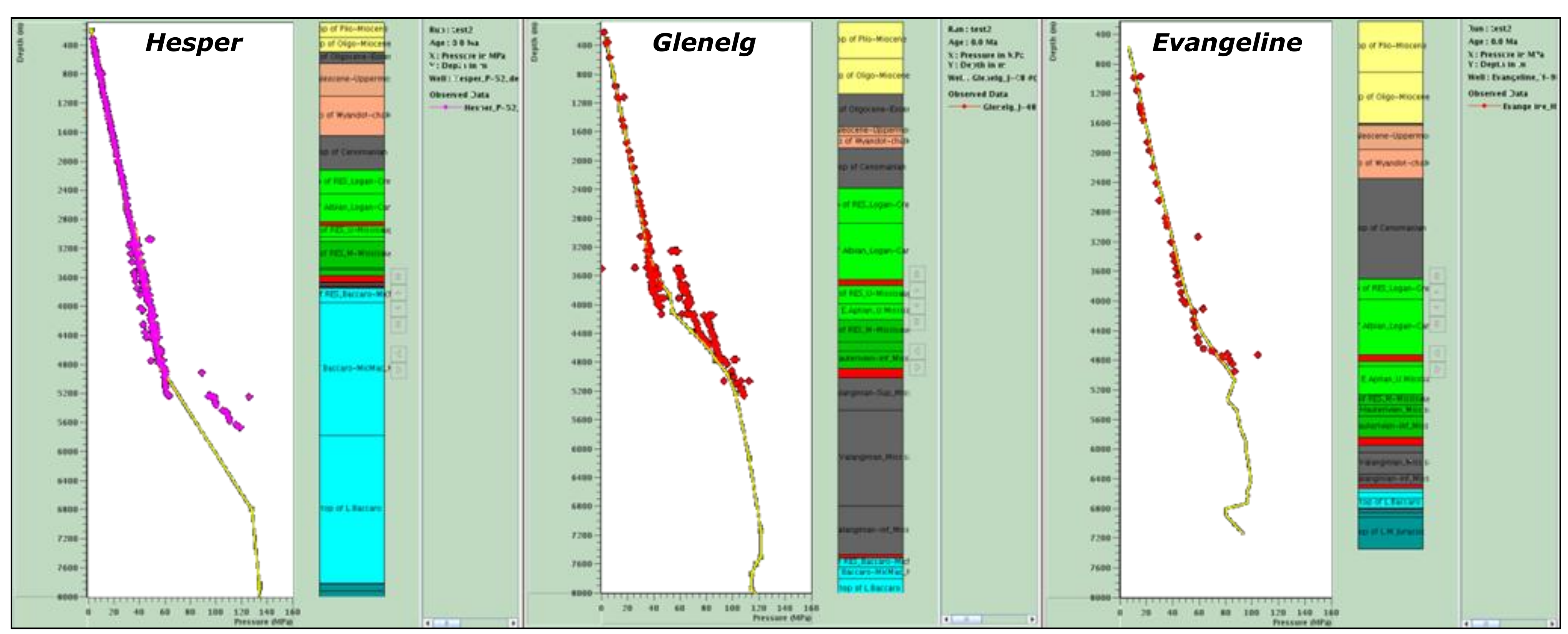


VITRINITE REFLEC. Calibration

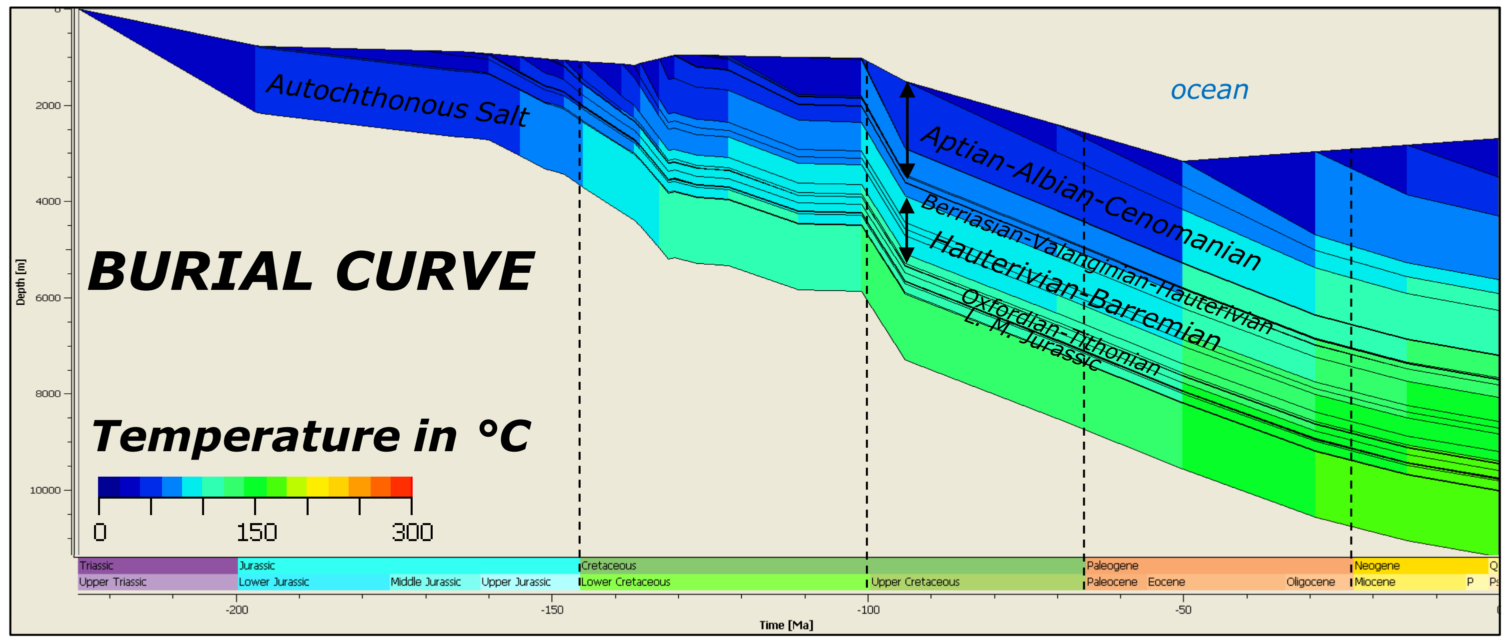
Calibrations

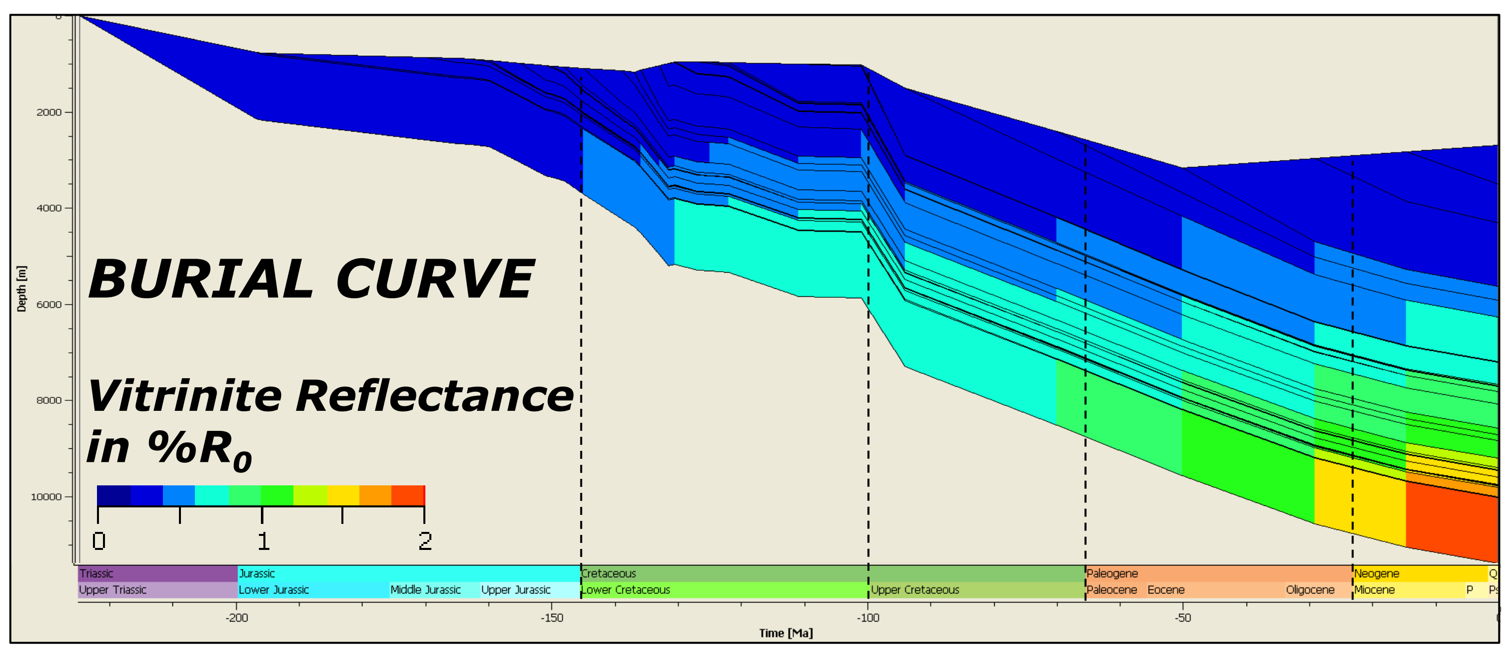
The 3D model is calibrated in pressure / temperature / maturity (vitrinite reflectance) with available well data. 31 wells are used. All wells are in zones 1, 3, 5, with a higher density in Zone 3 (sable Sub Basin – 16 wells used).

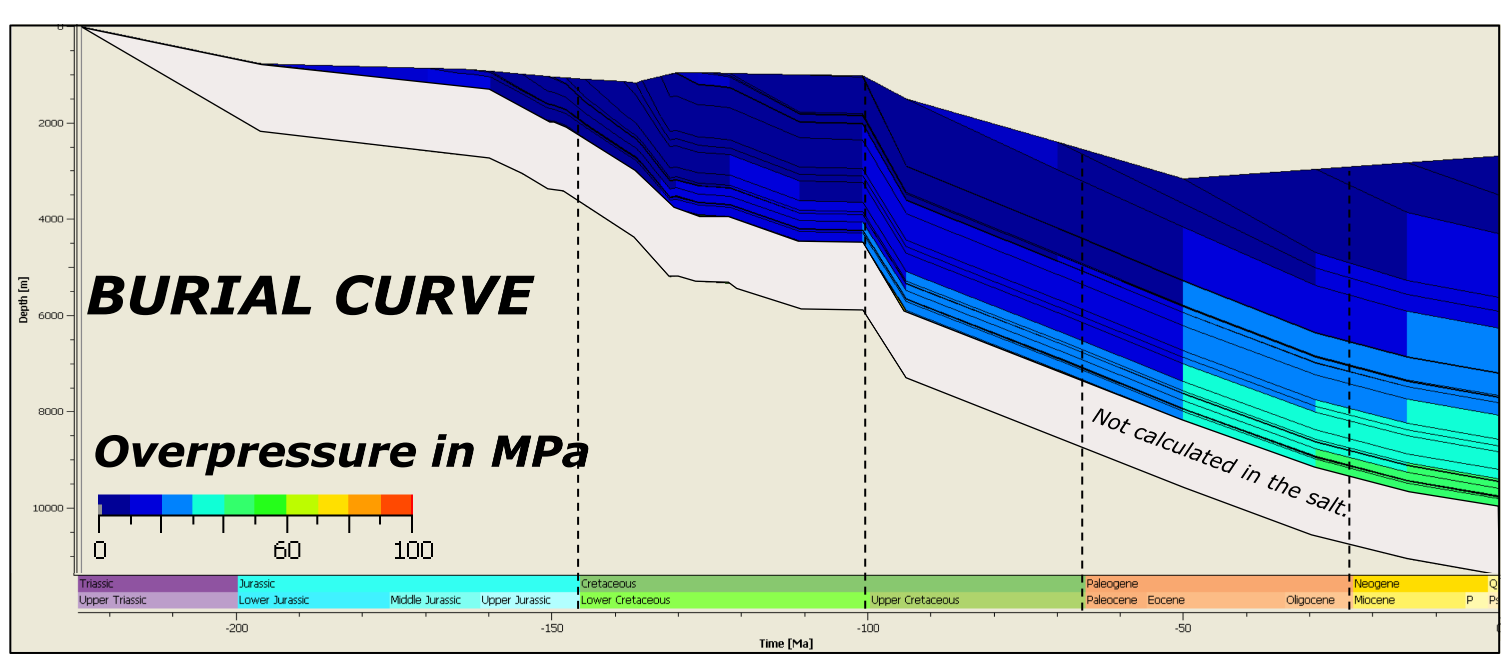
A second calibration phase uses well test data (API, GOR, oil and gas repartition within the Basin).

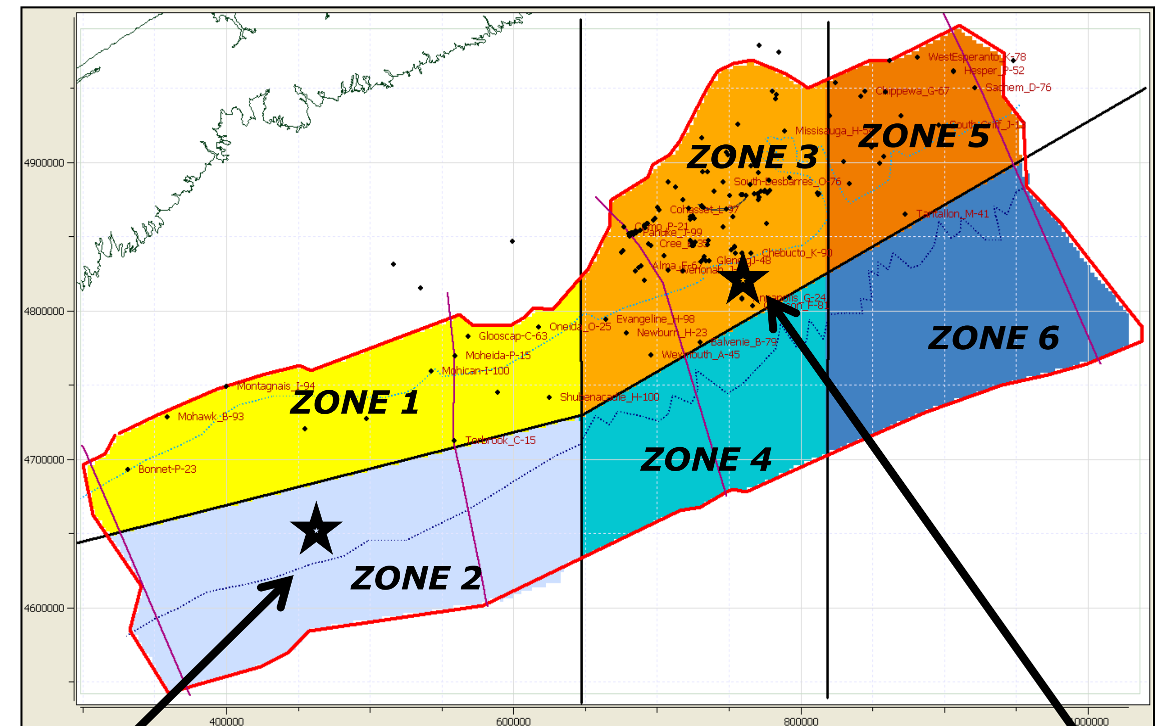


PRESSURE Calibration









Burial Curves gives the evolution of the burial through time, at a precise location in the Basin: (1) in the deep depression between Chebucto and Annapolis (Zone 3, on the right), (2) in a mini-basin of the salt basin (Zone 2, on the left).

Temperature, vitrinite, and overpressure evolution through time are indicated through time. Parameters are calculated at the cell center.

Temperature

Temperature are relatively low in that part of the Basin. The temperature reaches 170°C maximum, since Pliocene time (at 8 km of burial).

Vitrinite

Vitrinite reflectance reached 2% in the Pliensbachian SR (Lower Jurassic) during the Pliocene. The maturity level increased progressively since the Upper Cretaceous.

Overpressure

Moderate overpressure appeared progressively during the Tertiary. It is related to an increase of the burial, likely related to halokinesis and progressive salt withdrawal in the deepest part of the mini-basin.

Temperature

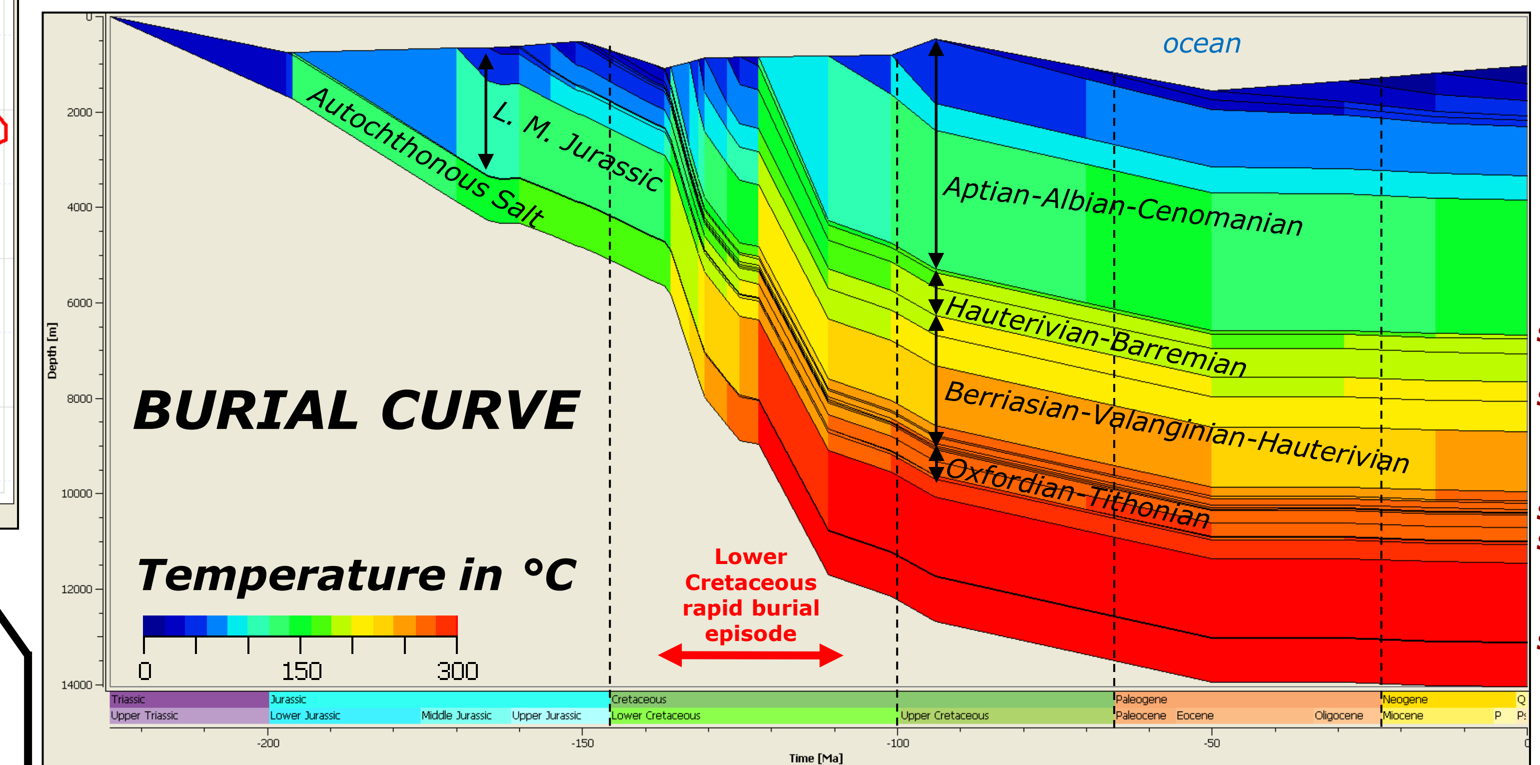
Temperature are relatively high in that part of the Basin. The temperature exceeds 300°C in the L. M. Jurassic since the Lower Cretaceous (11 km of burial at present day). In average, kerogens are overmature (above 200°C). A slight decrease of the thermal gradient occurred since the Lower Jurassic.

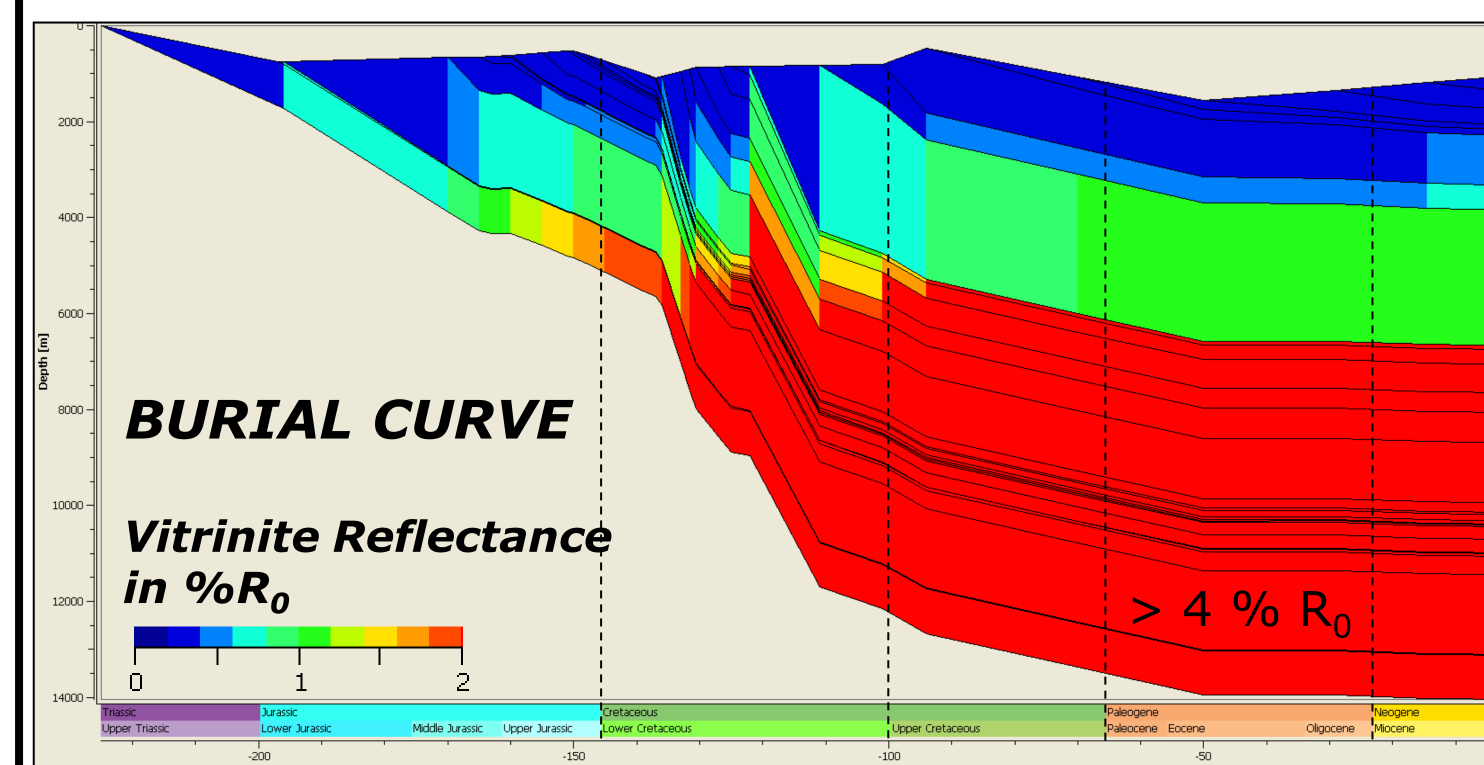
Vitrinite

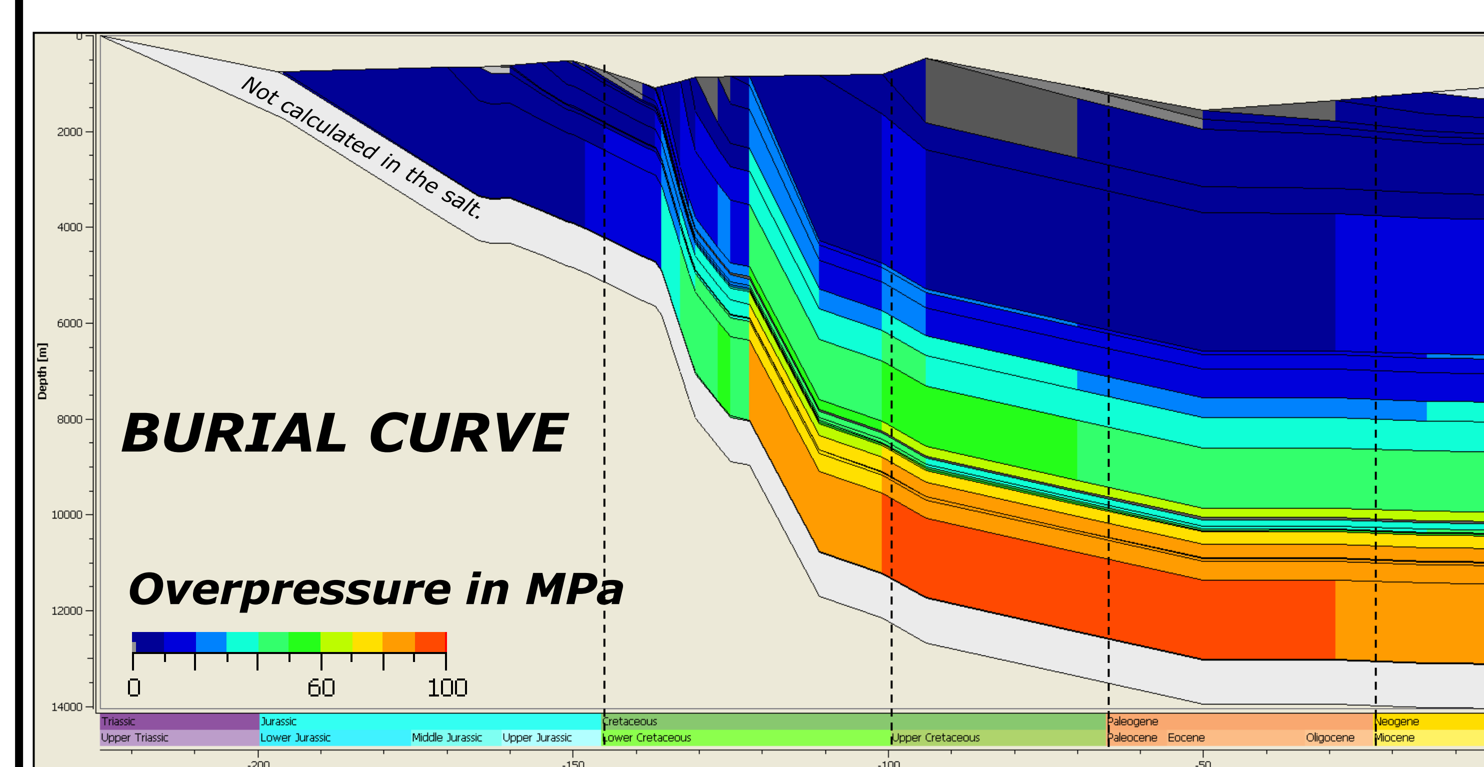
Vitrinite reflectance exceed 2% below the Aptian SR since Early Cretaceous time.

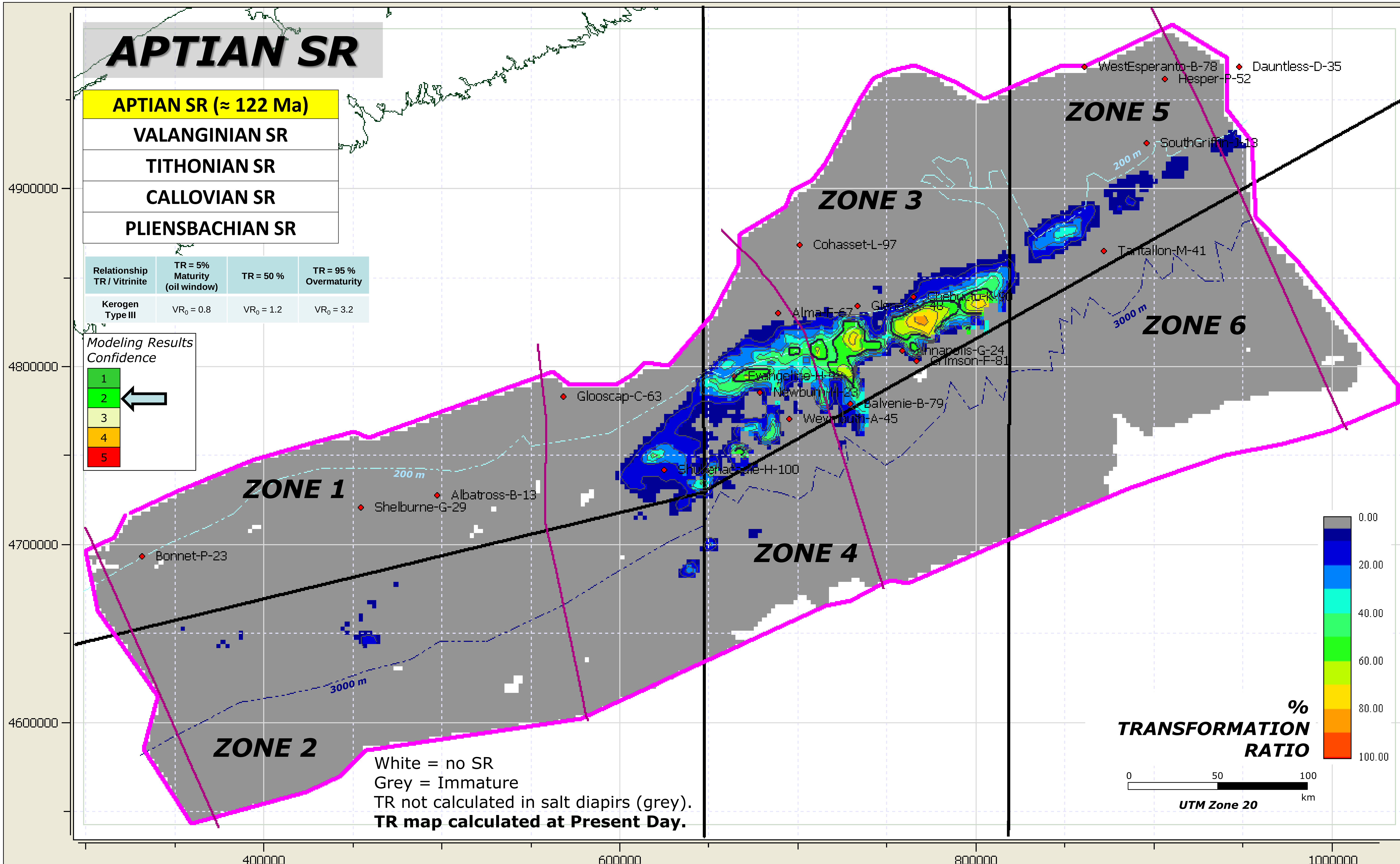
Overpressure

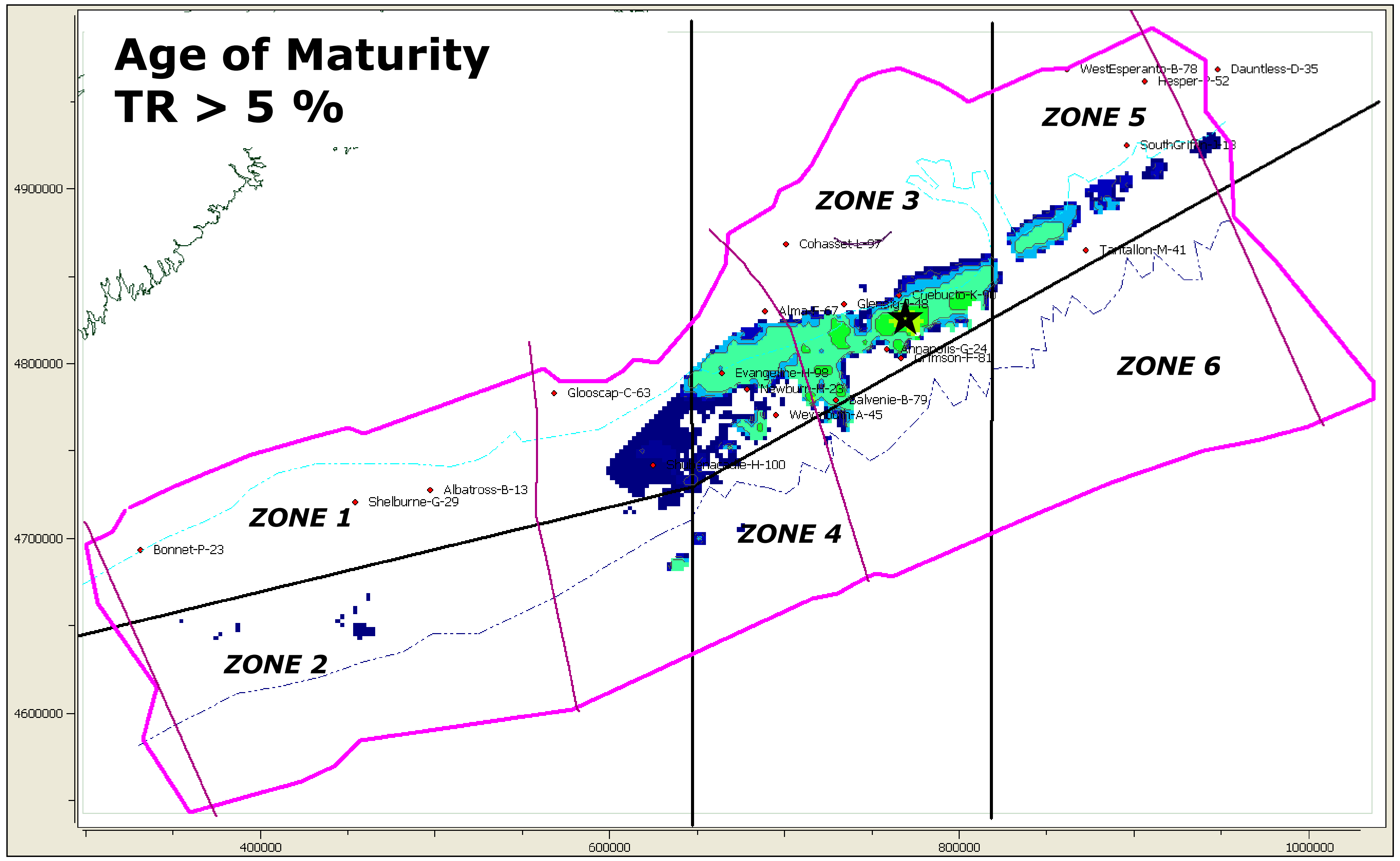
Overpressure appeared very early in the basin and is related to rapid burial during the Lower Cretaceous. It is mainly related to an excessive overburden (and under compaction). Hydrocarbon generation is a secondary cause. Overpressure tends to decrease since Late Cretaceous time.

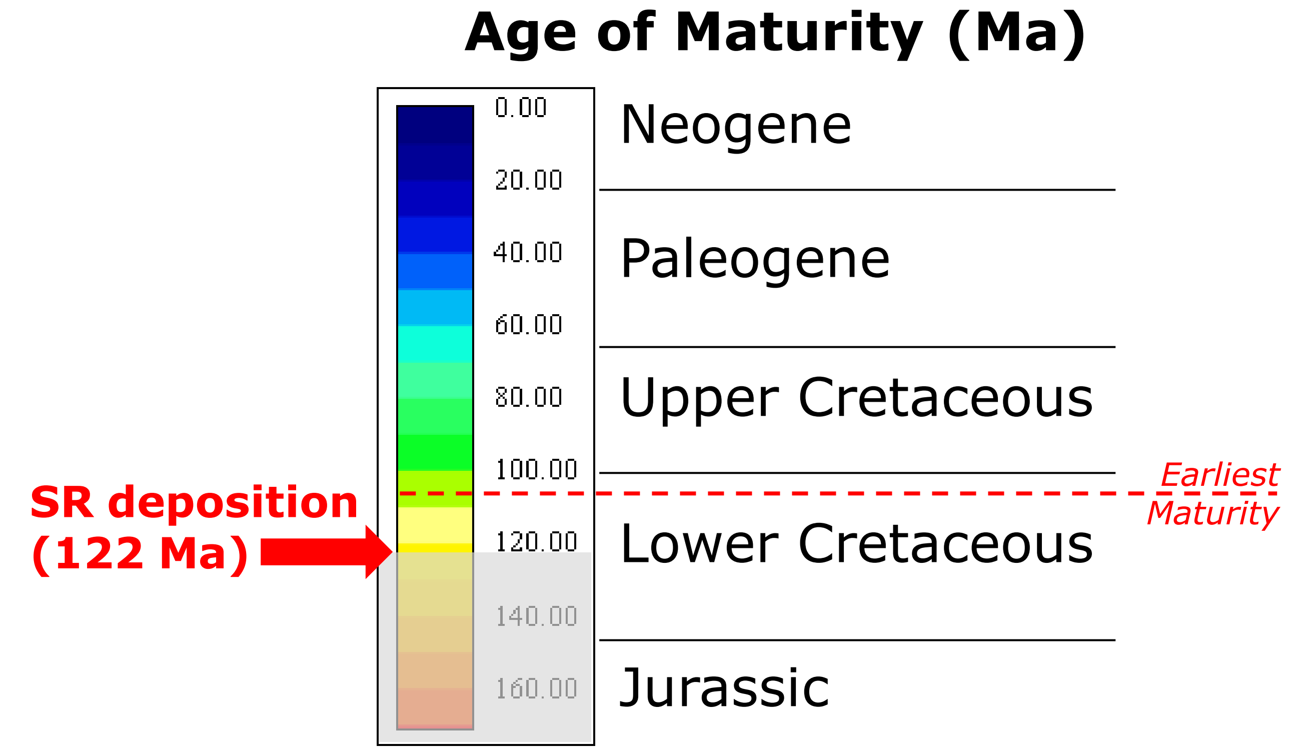


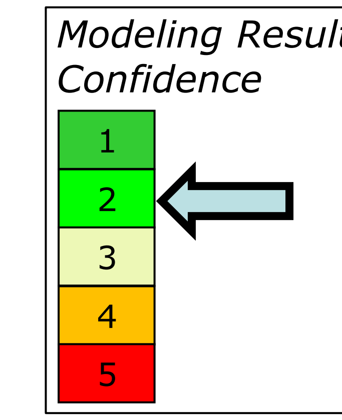





APTIAN SR
APTIAN SR (≈ 122 Ma)
VALANGINIAN SR
TITHONIAN SR
CALLOVIAN SR
PLIENSBACHIAN SR
Relationship TR / Vitrinite
TR = 5% Maturity (oil window)
TR = 50 %
TR = 95 % Overmaturity
Kerogen Type III
VR_0 = 0.8
VR_0 = 1.2
VR_0 = 3.2
Modeling Results Confidence
1
2
3
4
5
ZONE 1
ZONE 2
ZONE 3
ZONE 4
ZONE 5
ZONE 6
WestEsperanto-B-78
Dauntless-D-35
Hesper-P-52
SouthGriffin-J-13
Tantallon-M-41
Cohasset-L-97
Shebutu-K-14
Alma-F-67
Annapolis-G-24
Crimson-F-81
Evangeline-H-98
Newburn-H-23
Balvenie-B-79
Weymouth-A-45
Glooscap-C-63
Shubenacadie-H-100
Albatross-B-13
Shelburne-G-29
Bonnet-P-23
200 m
3000 m
4900000
4800000
4700000
4600000
400000
600000
800000
1000000
0.00
20.00
40.00
60.00
80.00
100.00
% TRANSFORMATION RATIO
0
50
100
km
UTM Zone 20
White = no SR
Grey = Immature
TR not calculated in salt diapirs (grey).
TR map calculated at Present Day.







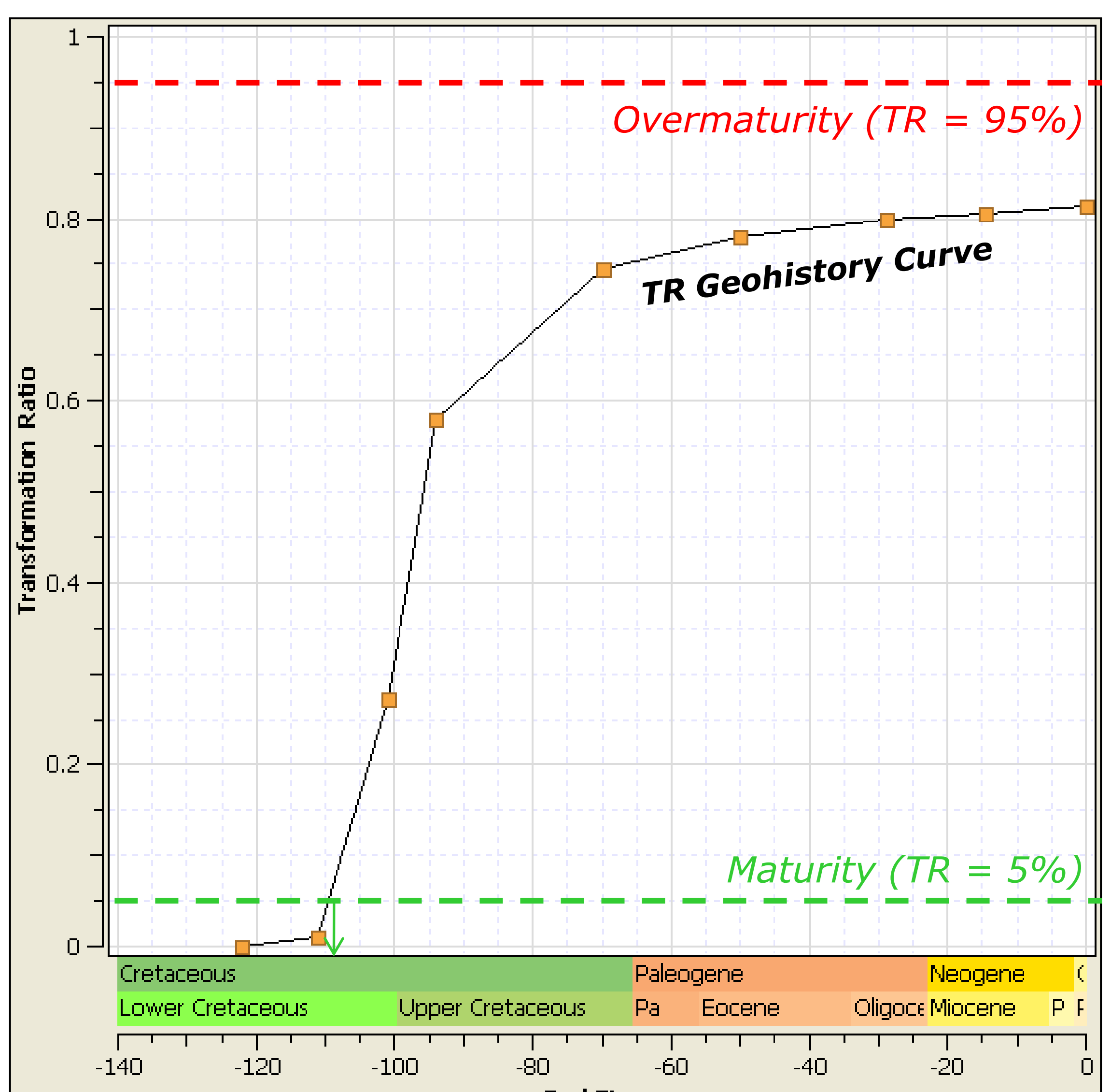
Age of maturity and of over-maturity (in Million Years)

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, 95% of Transformation Ratio for over-maturity.

Maturation of the Aptian SR started usually at the end of the Cretaceous in the depression south of Zone 3, and locally earlier between Glenelg and Annapolis. Maturity is very recent in the easternmost part of Zone 3.

The Aptian SR did not reach the over-maturity level.

APTIAN SR



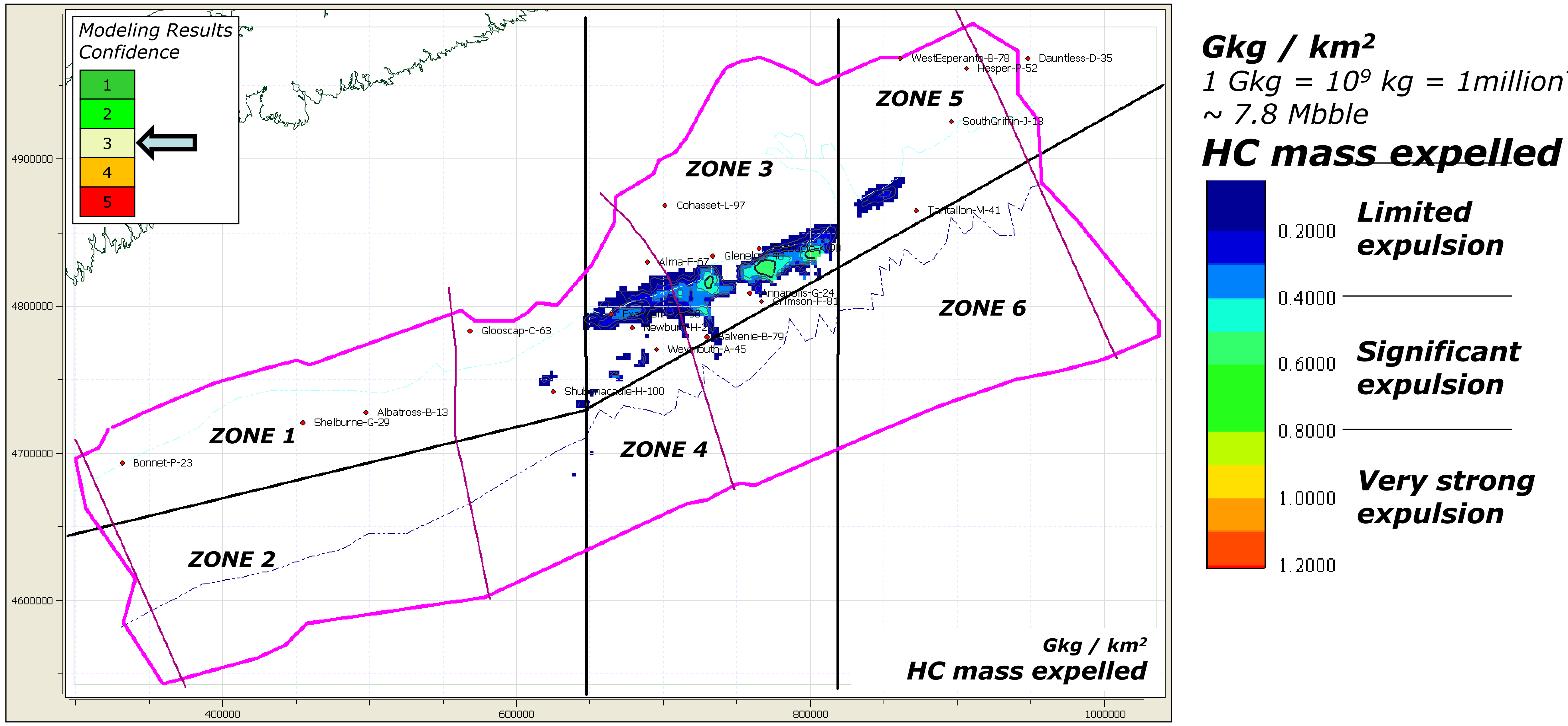
Evolution of the Maturity

in the deep mini-basin between Chebucto and Annapolis

The graph indicates the evolution of the Transformation Ratio through time at the deepest point of the mini-basin located between Chebucto and Annapolis (black star on maps, Zone 3, south of the shelf break). This is one of the most mature zone in the Basin.

At this location, the Aptian SR is not overmature. It experienced 1 main phase of maturation related to the end of the Lower Cretaceous rapid burial episode: between 110 and 90 Ma.
Since that time the maturation speed decreased progressively. This part of the basin is almost inactive (from the generation / expulsion point of view) since Eocene time.

3D Maturity / Expulsion Modeling – APTIAN SR – Maturity Timing Maps and Graphs



Gkg / km²

1 Gkg = 10^9 kg = 1millionT

~ 7.8 Mbble

HC mass expelled

Expulsion Map at Present Day (by square kilometer)

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 this study case, it is unlikely that zones with expulsion lower than 0.4 Gkg / km² (~ 3.1 Mbble / km²) significantly contribute to an active petroleum system.
To convert HC mass (Gkg) in equivalent barrels of oil (Million bble), multiply values by about 8 (average oil density estimated at 810 kg/m³).

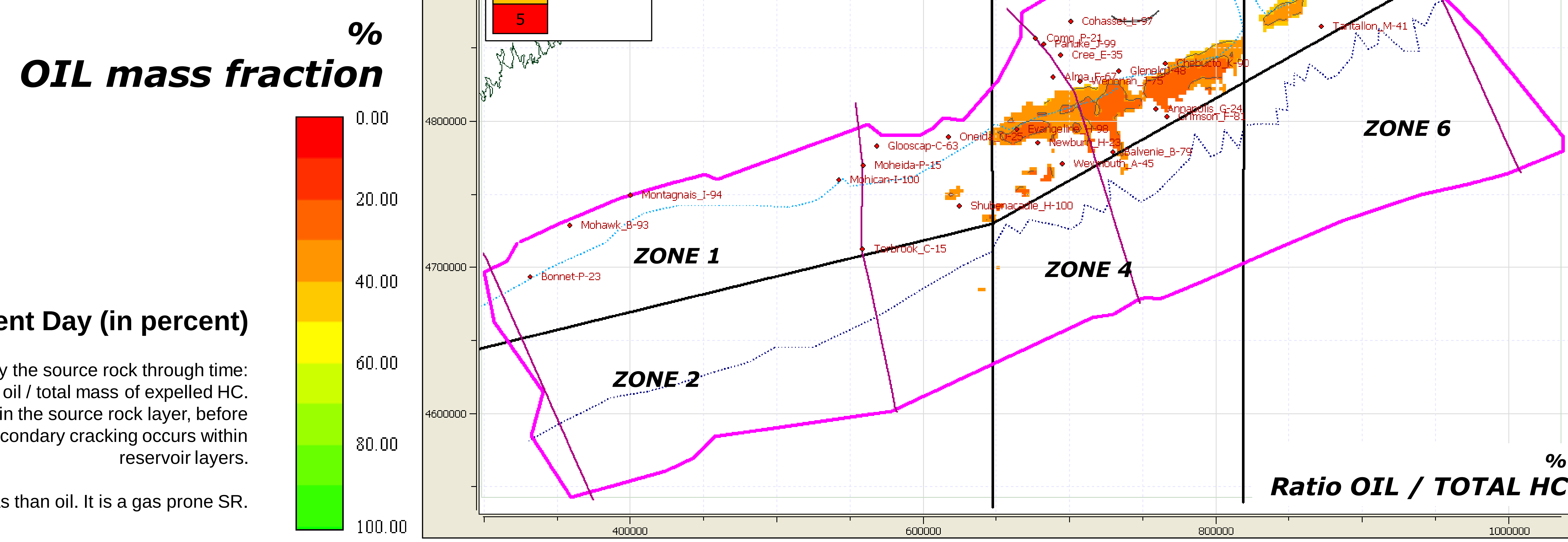
Expulsion mainly occurs in Zone 3. It is not very significant except locally in the deepest part of the depression between Glenelg and Annapolis.

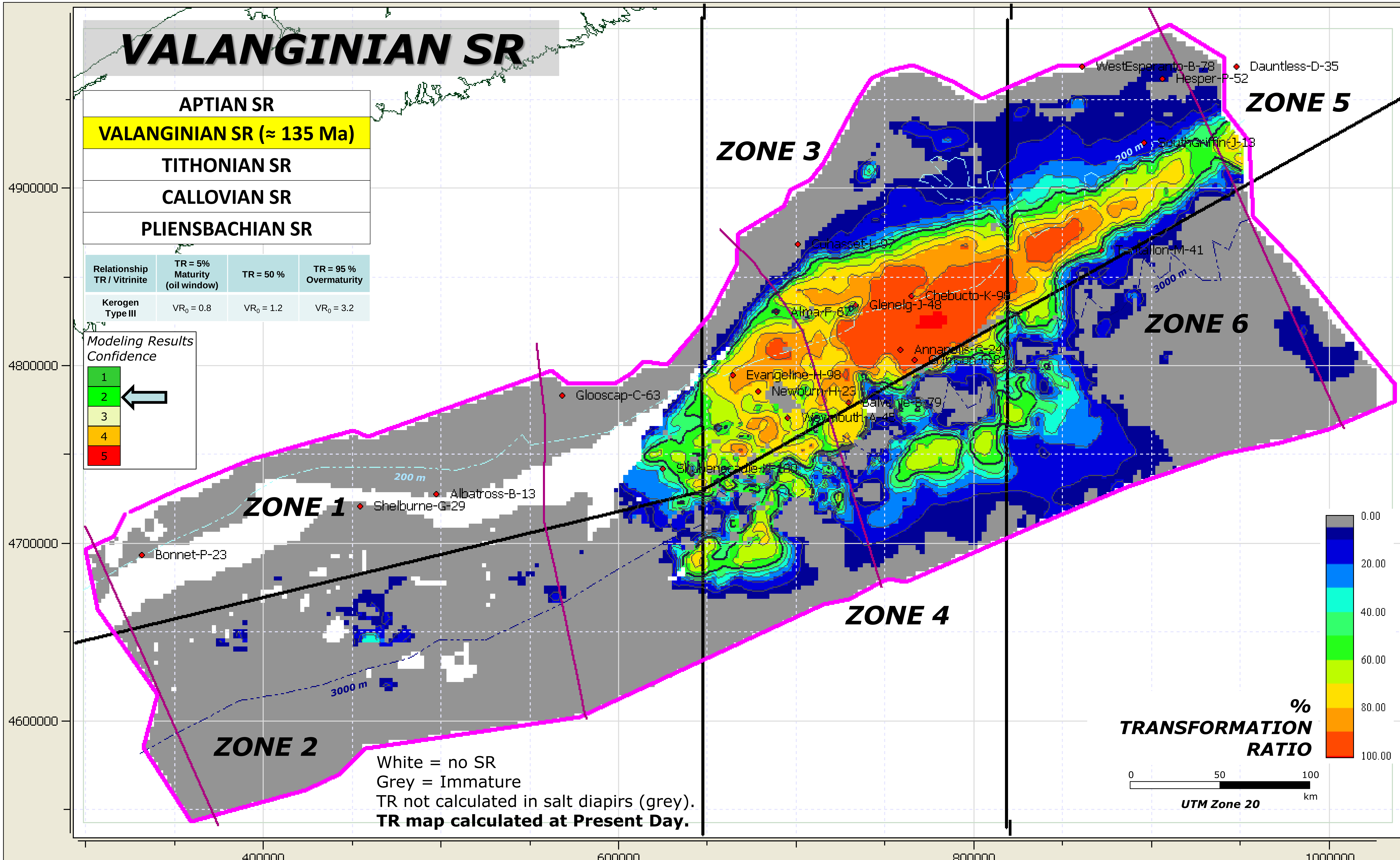
APTIAN SR

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 takes into account secondary cracking of heavy HC occurring within the source rock layer, before expulsion, but cannot be representative of the amount of oil in place if secondary cracking occurs within reservoir layers.

Despite a relatively low maturity level, this SR expels more gas than oil. It is a gas prone SR.




VALANGINIAN SR
APTIAN SR
VALANGINIAN SR (≈ 135 Ma)
TITHONIAN SR
CALLOVIAN SR
PLIENSBACHIAN SR
Relationship TR / Vitrinite
TR = 5% Maturity (oil window)
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TR = 95 % Overmaturity
Kerogen Type III
VR0 = 0.8
VR0 = 1.2
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Modeling Results Confidence
1
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ZONE 1
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ZONE 6
WestEsperanto-B-78
Dauntless-D-35
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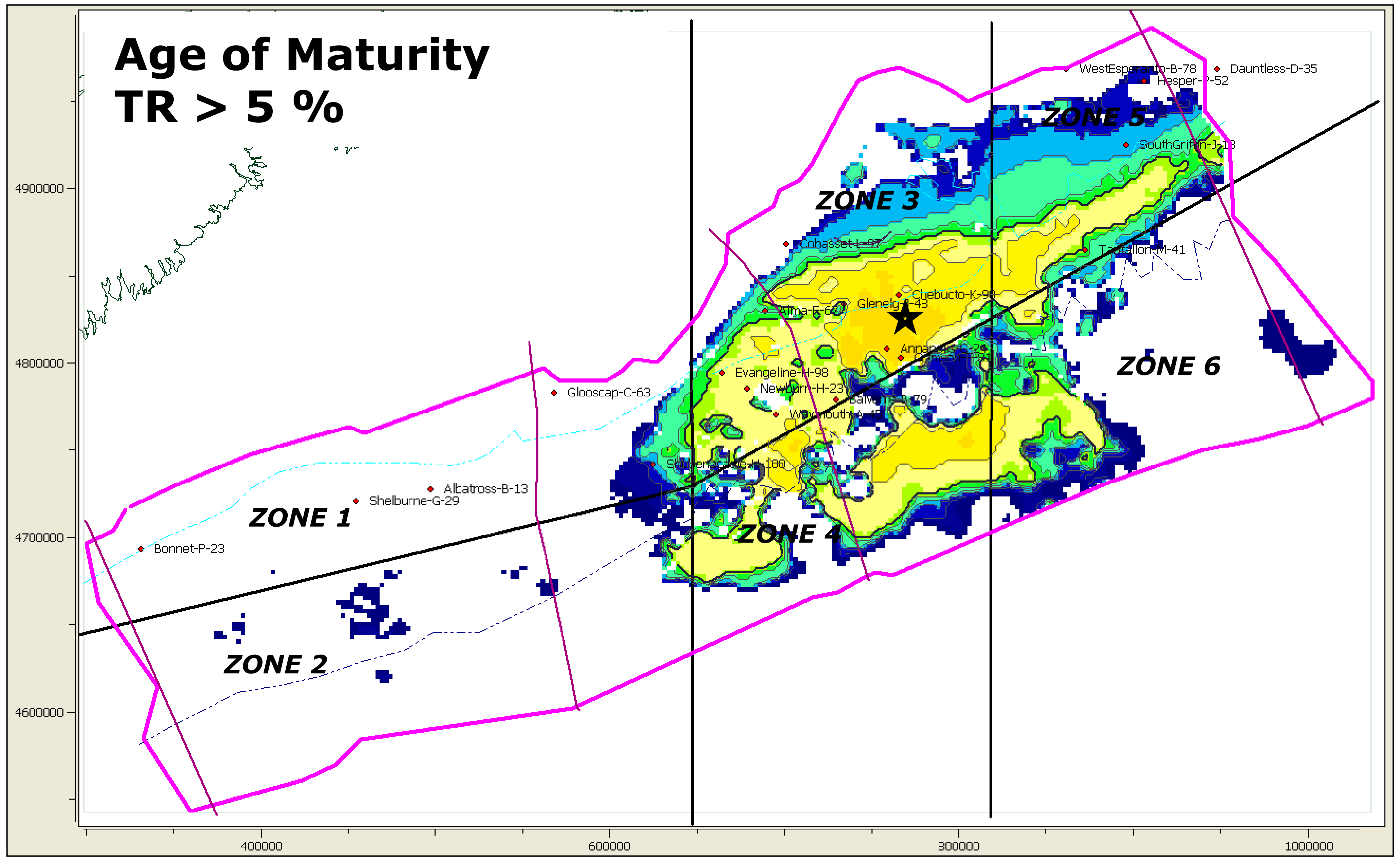
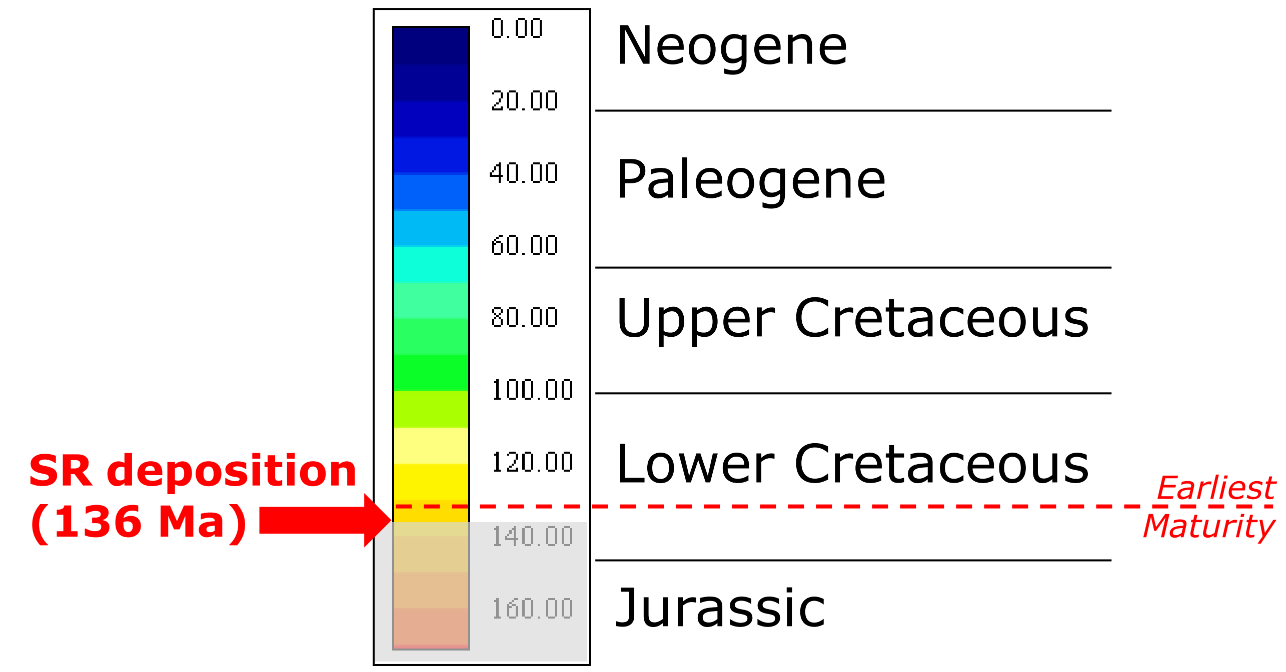
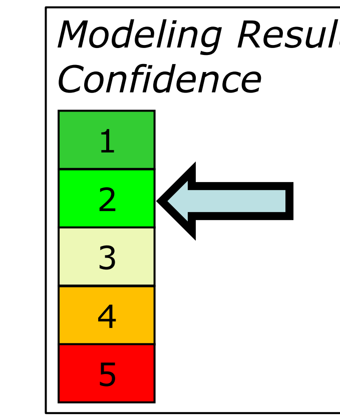
SouthGriffin-J-13
Mohican-I-100
Tantallon-M-41
Chebucto-K-90
Glenelg-J-48
Alma-F-67
Annapolis-G-24
Evangeline-H-98
Newburn-H-23
Weymouth-A-45
Glooscap-C-63
Albatross-B-13
Shelburne-G-29
Bonnet-P-23
200 m
3000 m
White = no SR
Grey = Immature
TR not calculated in salt diapirs (grey).
TR map calculated at Present Day.
%
TRANSFORMATION RATIO
0.00
20.00
40.00
60.00
80.00
100.00
0
50
100
km
UTM Zone 20
4900000
4800000
4700000
4600000
400000
600000
800000
1000000



Age of Maturity (Ma)





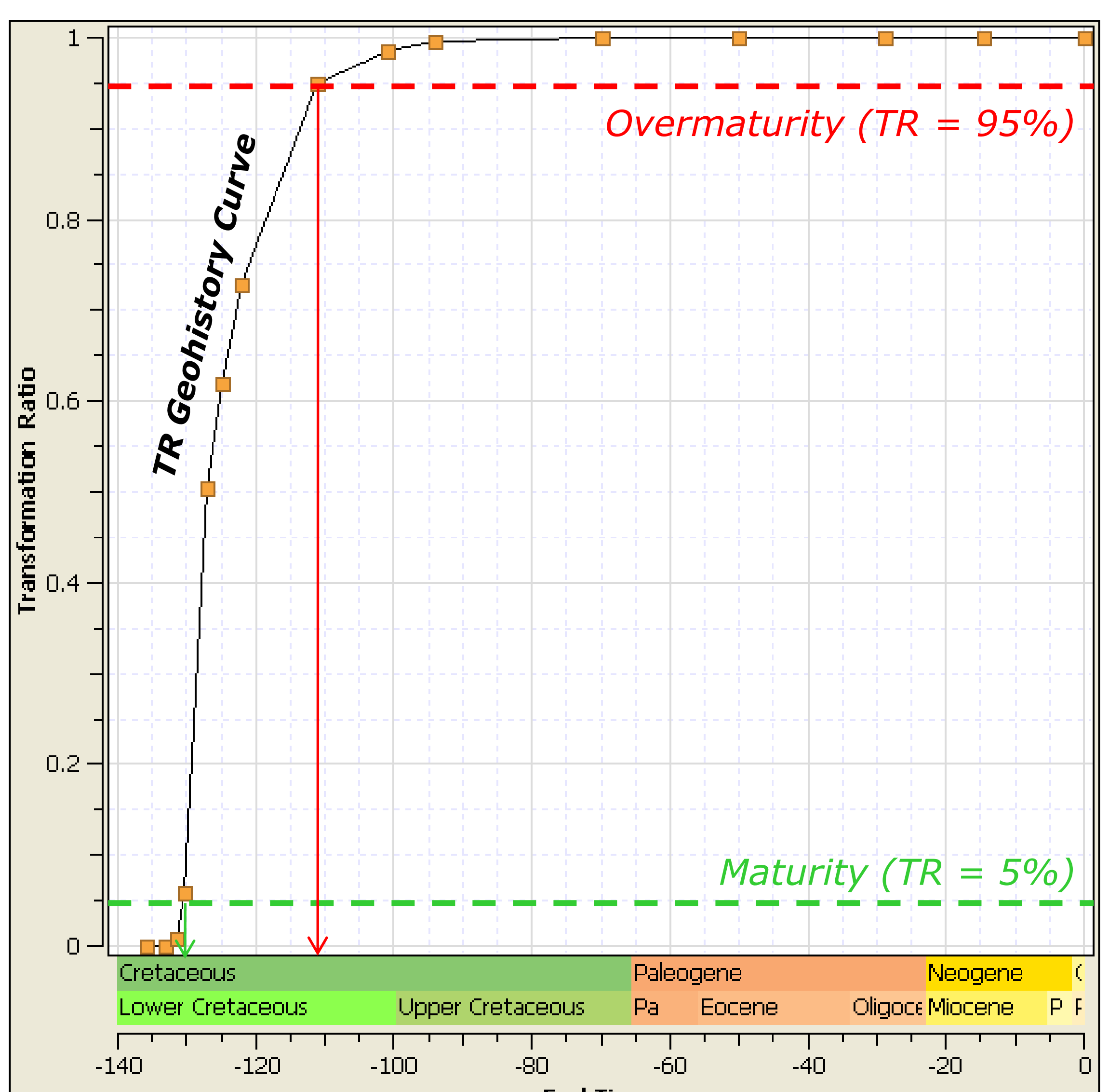
Age of maturity and of over-maturity (in Million Years)

Maps indicate the age at which the source rock reached a given level of maturity: 5% of Transformation Ratio for the beginning of maturity, 95% of Transformation Ratio for over-maturity.

Maturation of the Valanginian SR started early in the depression south of Zone 3 and Zone 5, and in a wide part of Zone 4, usually 20 – 30 Ma after the SR deposition (Lower Cretaceous). Maturity is more recent on the platform in Zone 3 and 5 (Latest Cretaceous and Paleogene).

The Valanginian SR reached the over-maturity level early in the deepest part of the depression between Glenelg and Annapolis (about 110 Million years ago).

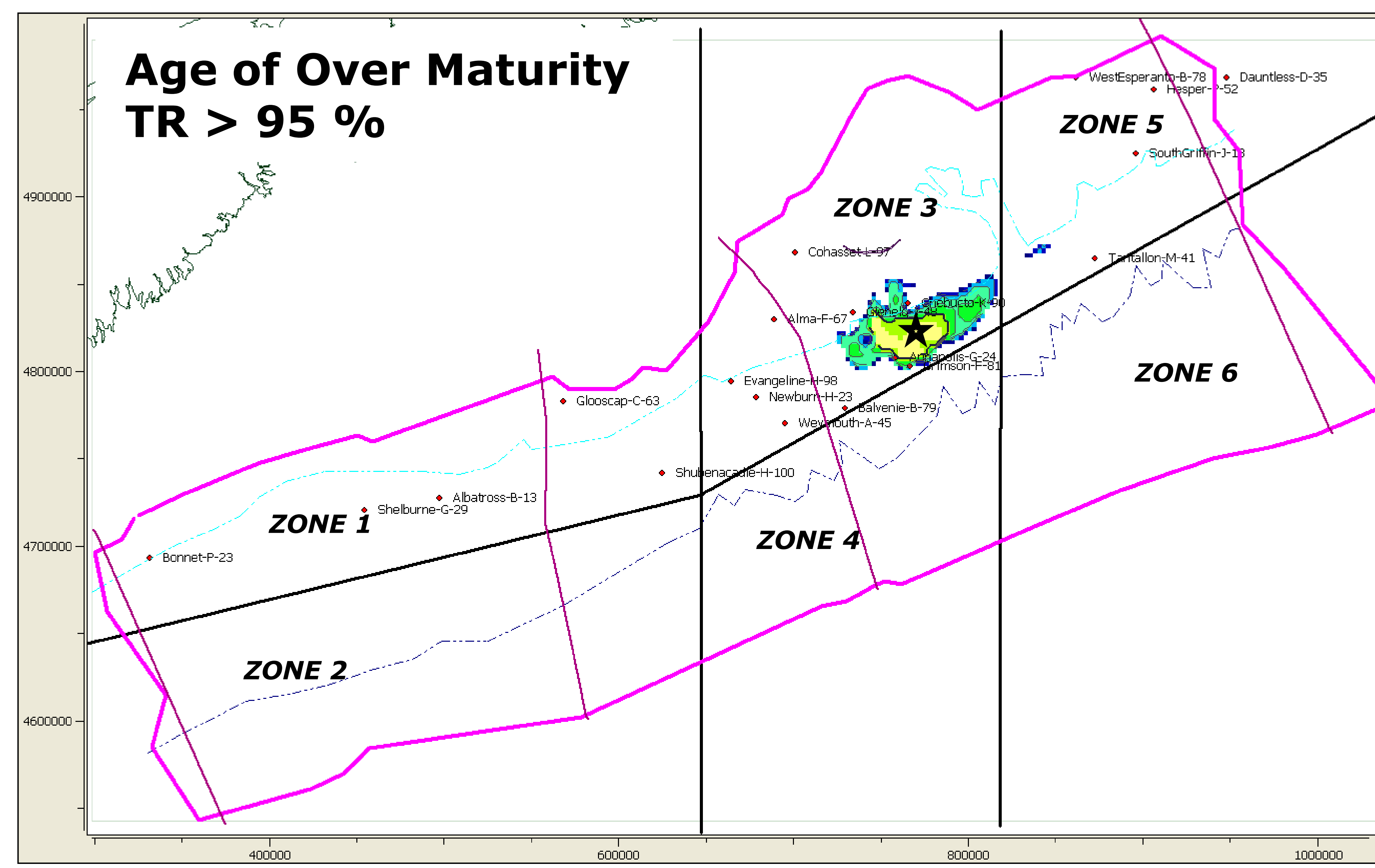
VALANGINIAN SR



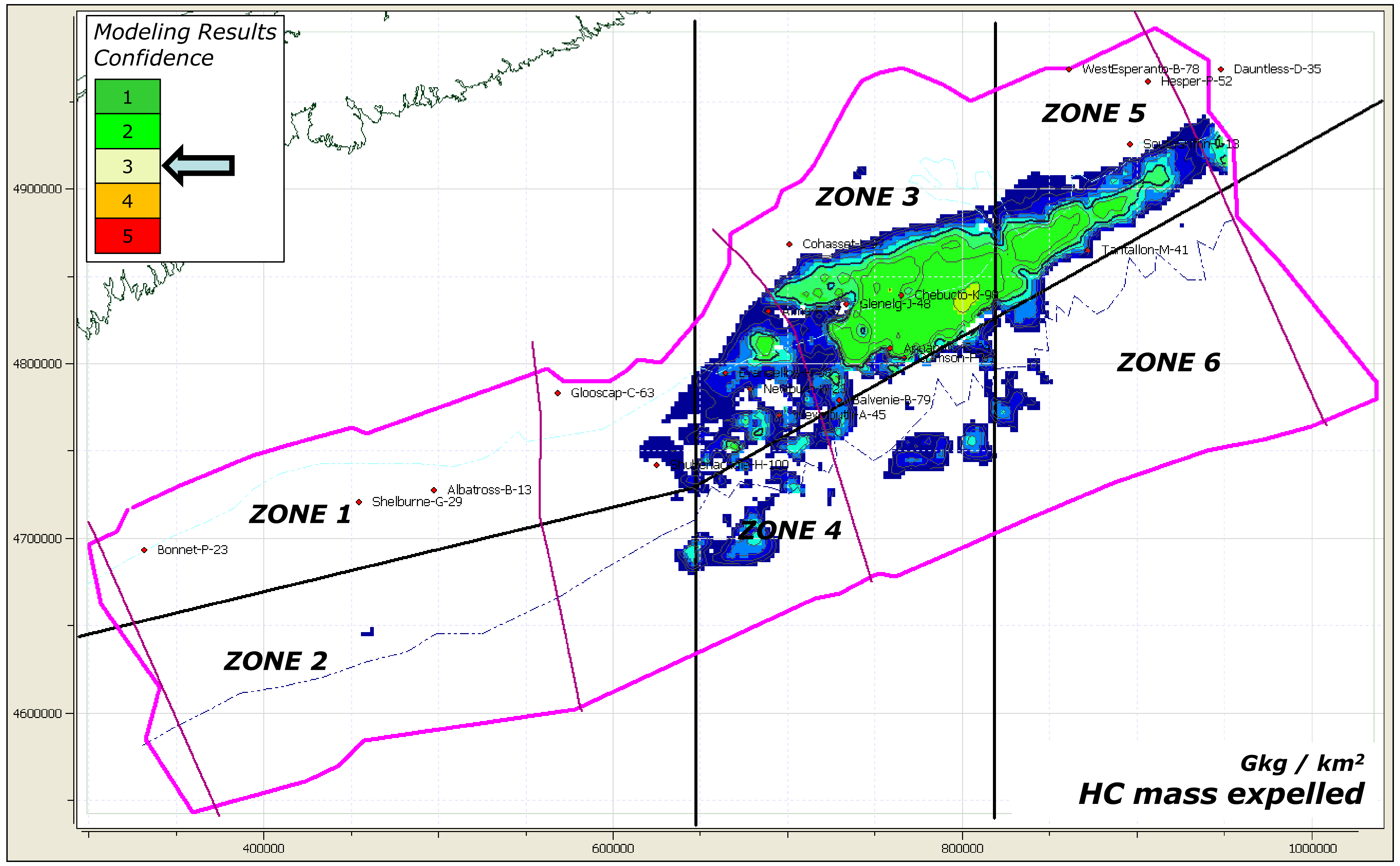
Evolution of the Maturity in the deep mini-basin between Chebucto and Annapolis

The graph indicates the evolution of the Transformation Ratio through time at the deepest point of the mini-basin located between Chebucto and Annapolis (black star on maps, Zone 3, south of the shelf break). This is one of the most mature zone in the Basin.

At this location, the Valanginian SR experienced 1 main phase of maturation related to the Lower Cretaceous rapid burial episode: between 130 and 110 Ma for this source rock. The decrease of the maturation speed after 110 Ma is more related to a specificity of the kerogen kinetic than to a decrease of the burial rate.



3D Maturity / Expulsion Modeling – VALANGINIAN SR – Maturity Timing Maps and Graphs

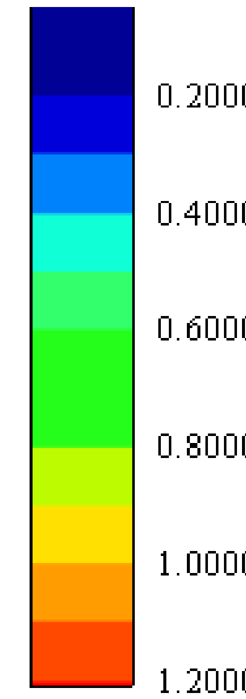


Gkg / km²

1 Gkg = 10^9 kg = 1 Million T

~ 7.8Mbble

HC mass expelled



Expulsion Map at Present Day (by square kilometer)

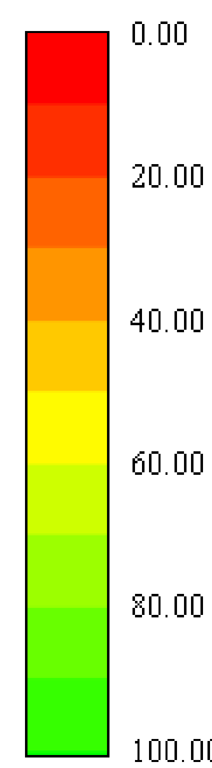
The map gives HC mass expelled through time (cumulated mass).
HC mass expelled = oil mass expelled + gas mass expelled
Expulsion process corresponds to primary migration of HC out of SR layers.
Expelled volumes are smaller than generated volumes and depend on petrophysical properties of source rocks (porosity, relative permeabilities 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 0.4 kg / km^2 (~ 3.1 Mbble / km^2) significantly contribute to an active petroleum system.
To convert HC mass (Gkg) in equivalent barrels of oil (Million bble), multiply values by about 8 (average oil density estimated at 810 kg/m^3).

Expulsion is mainly significant in Zone 3 and 5. In Zone 4 expulsion remained limited, and elsewhere (Zone 1, 2, 6) Valanginian source rock did not contribute to any charge.

VALANGINIAN SR

%

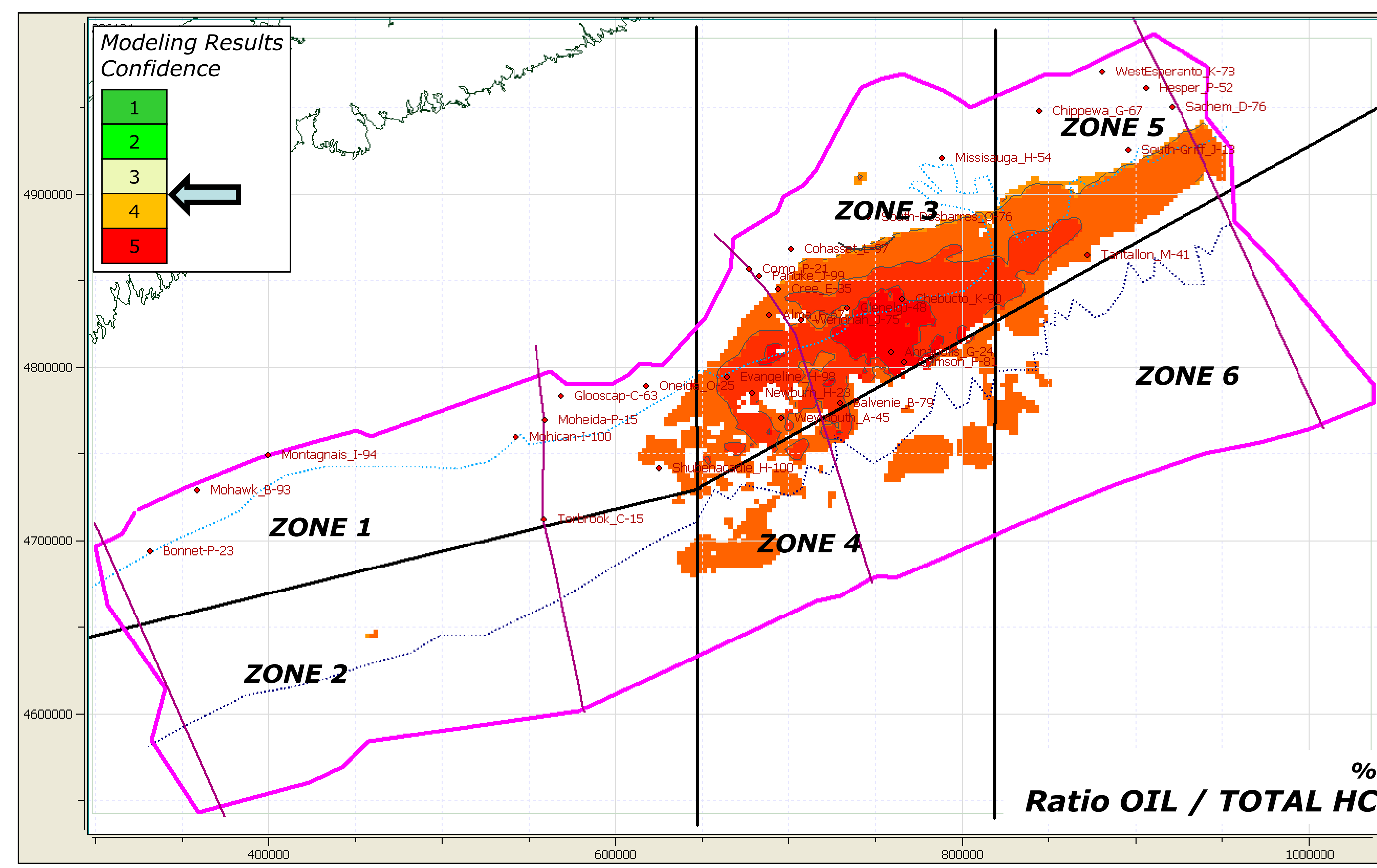
OIL mass fraction

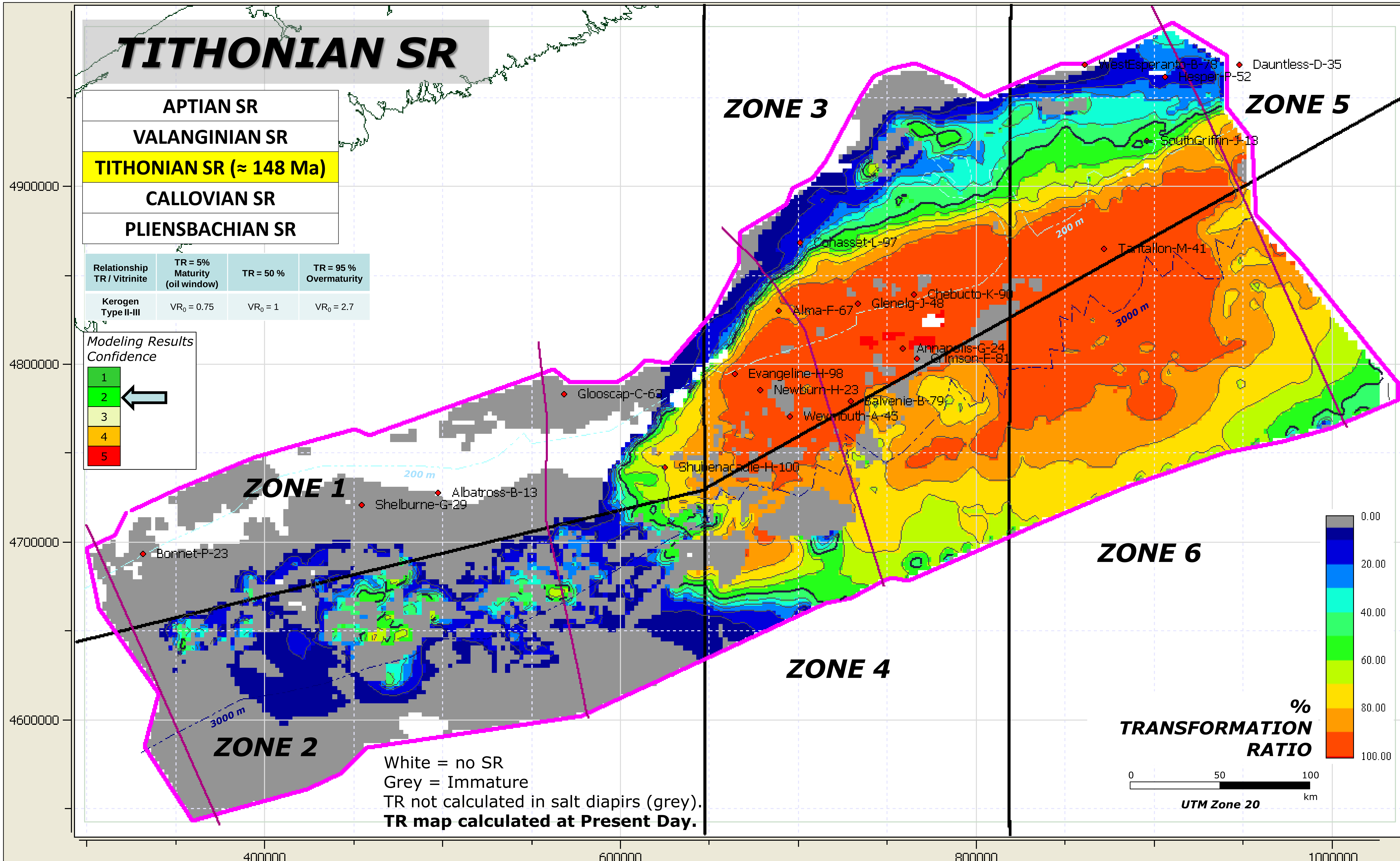


OIL /TOTAL HC Ratio Map at Present Day (in percent)

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 takes into account secondary cracking of heavy HC occurring within the source rock layer, before expulsion, but cannot be representative of the amount of oil in place if secondary cracking occurs within reservoir layers.

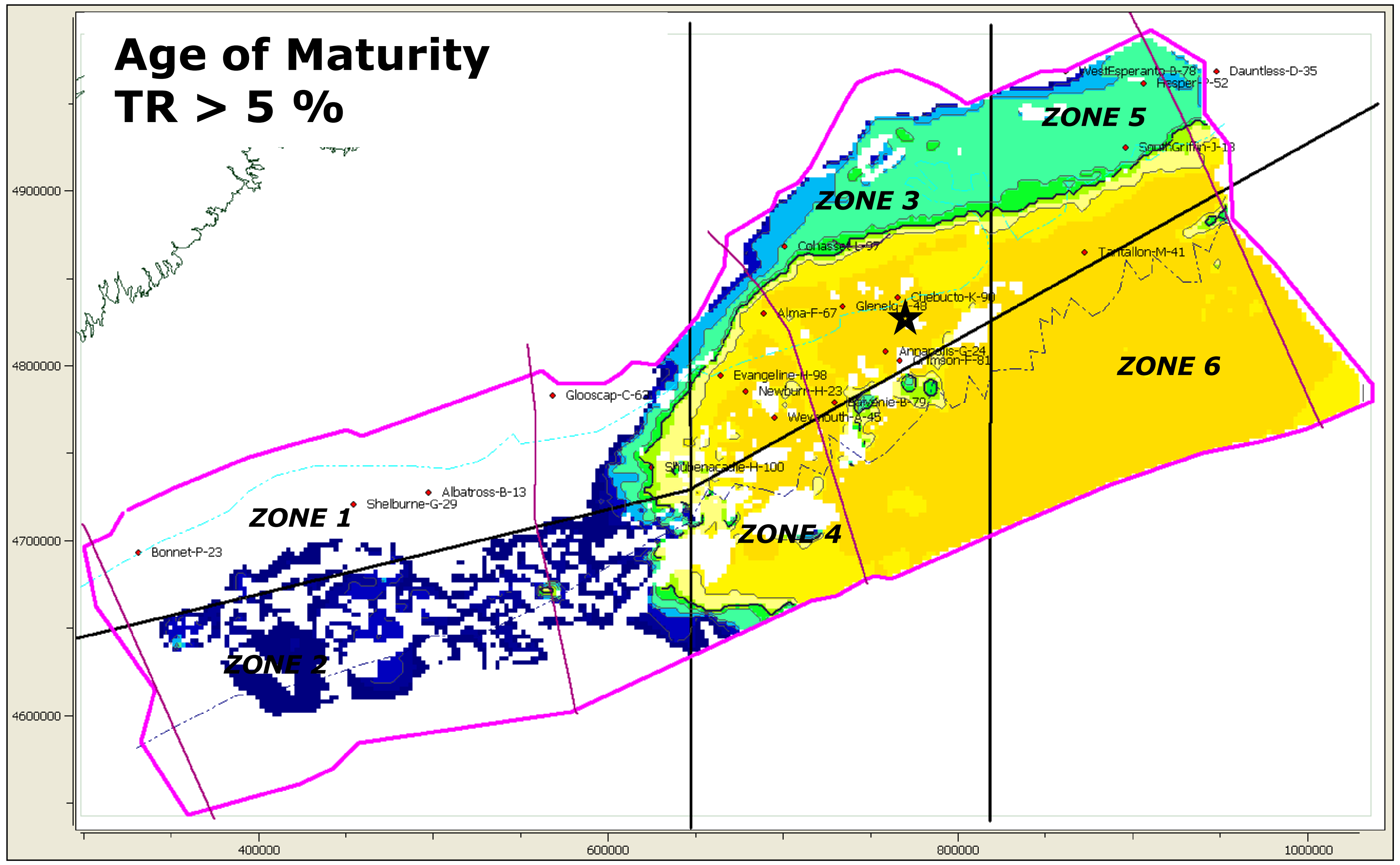
The Valanginian SR expelled more gas than oil. It is a gas prone SR.
The amount of oil fraction is predominantly between 20% and 30% at the exception of the deepest part of the basin where secondary cracking in the SR occurs significantly. In the deepest part the oil fraction is less than 20%, and can be less than 10%.



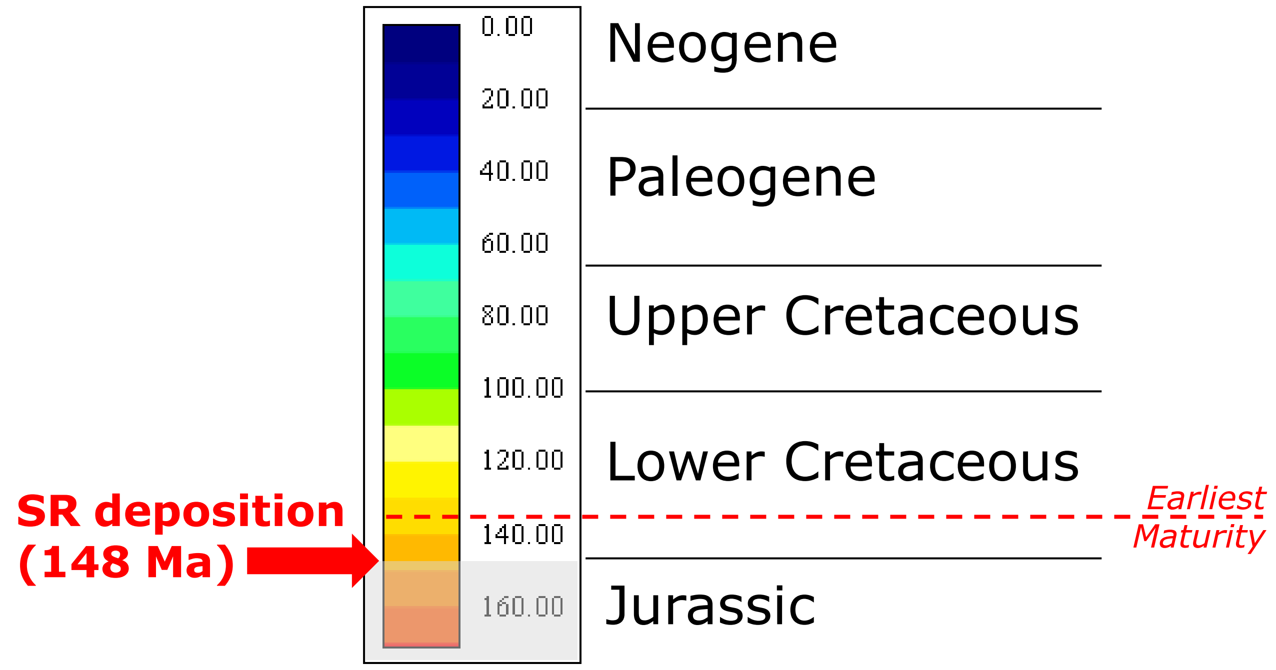


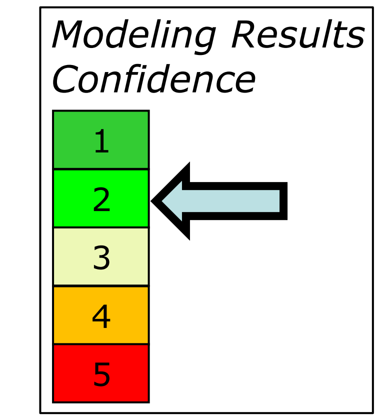
3D Maturity / Expulsion Modeling – TITHONIAN SR – Transformation Ratio Map

PL. 7-3-2-6



Age of Maturity (Ma)

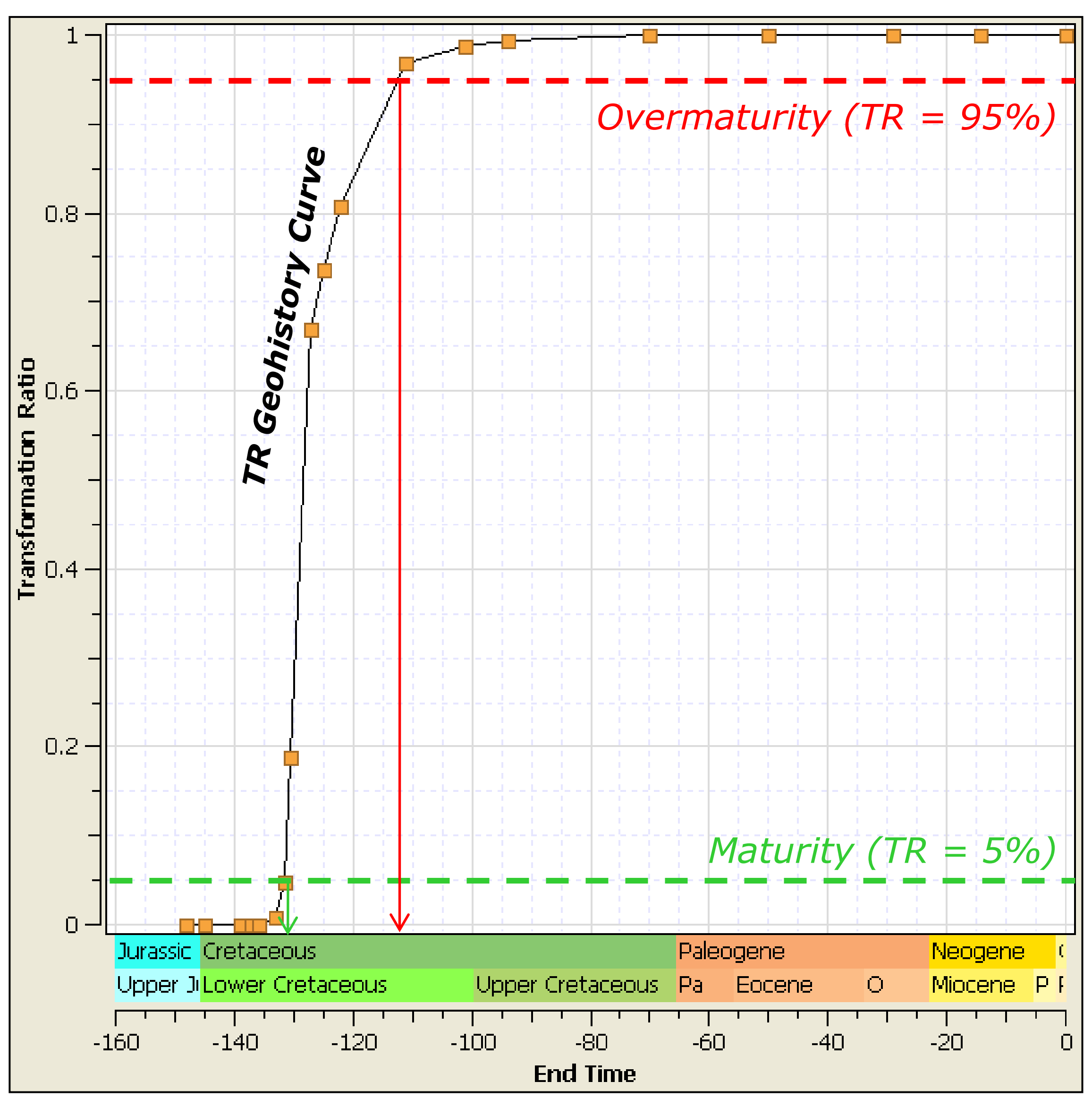




Age of maturity and of over-maturity (in Million Years)

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, 95% of Transformation Ratio for over-maturity.
Maturation of the Tithonian SR started at Lower Cretaceous in the zones 3, 4, 5 and 6. On the contrary, maturation started very lately in the western area (zones 1 and 2).
The second map indicates at which age the source rock reached over maturity (TR>95%). This over maturity is very early (Lower Cretaceous) for the deepest part of zones 3, 5 and 6 that are located on the slope.

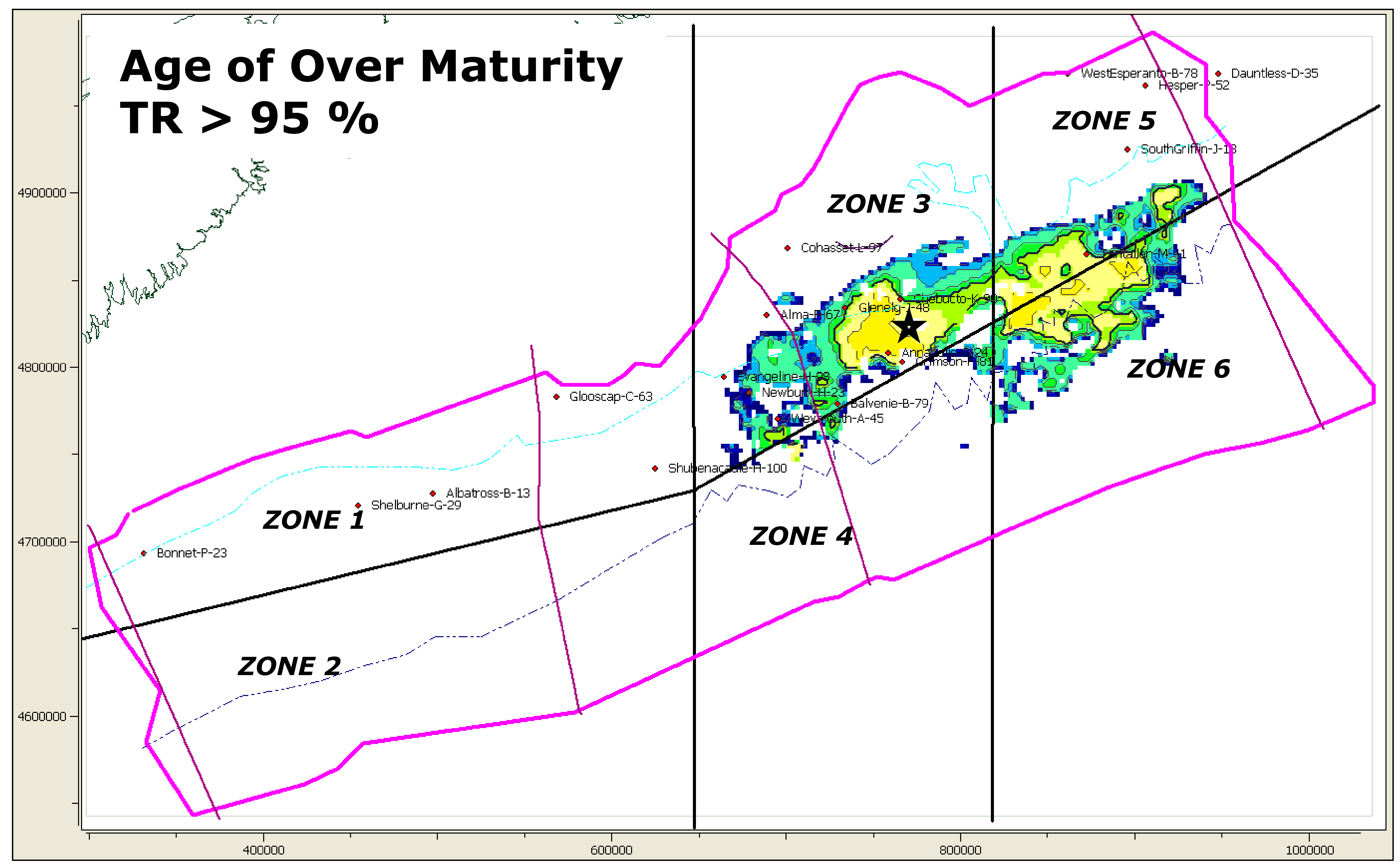
TITHONIAN SR

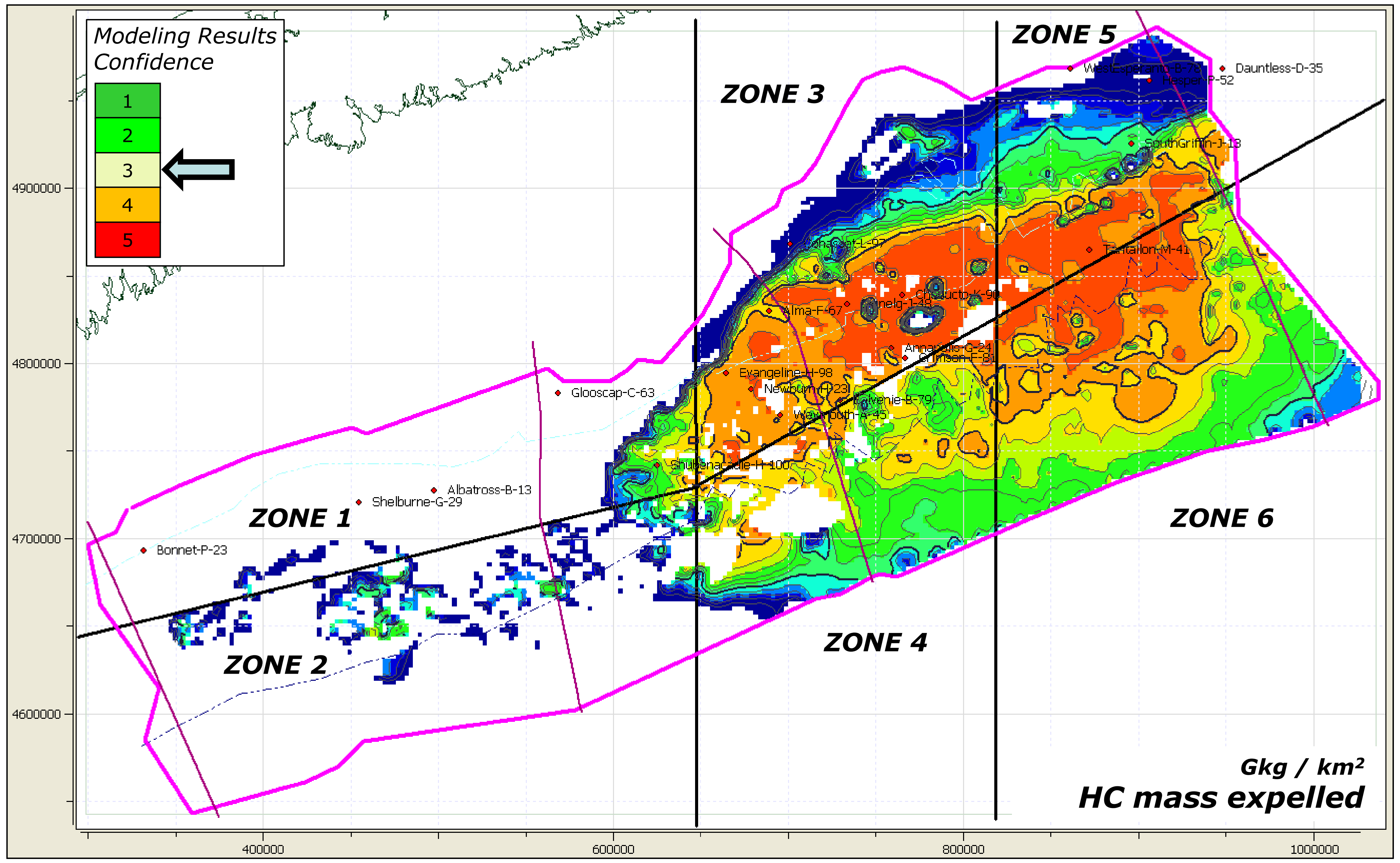


Evolution of the Maturity in the deep mini-basin between Chebucto and Annapolis

The graph indicates the evolution of the Transformation Ratio through time at the deepest point of the mini-basin located between Chebucto and Annapolis (black star on maps, Zone 3, south of the shelf break). This is one of the most mature zone in the Basin.

At this location, the Tithonian SR experienced 1 main phase of maturation related to the Lower Cretaceous rapid burial episode: between 130 and 110 Ma. The decrease of the maturation speed after 110 Ma is more related to a specificity of the kerogen kinetic than to a decrease of the burial rate.



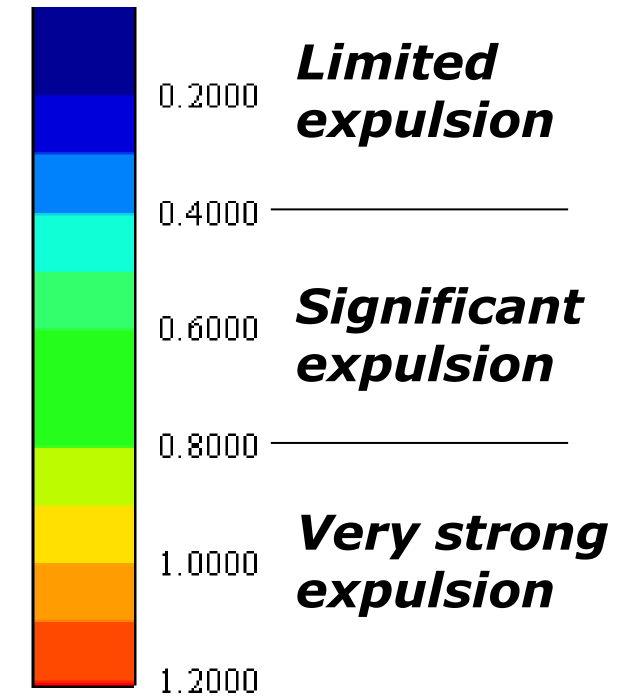


Gkg / km²

1 Gkg = 10^9 kg = 1 Million T

~ 7.8 Mbble

HC mass expelled



Expulsion Map at Present Day (by square kilometer)

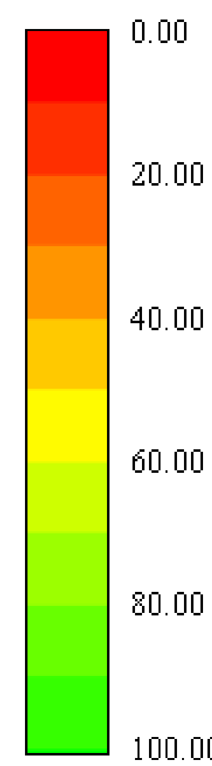
The map gives HC mass expelled through time (cumulated mass).
HC mass expelled = oil mass expelled + gas mass expelled
Expulsion process corresponds to primary migration of HC out of SR layers.
Expelled volumes are smaller than generated volumes and depend on petrophysical properties of source rocks (porosity, relatives permeability between hydrocarbons and water, irreducible water saturation, capillary pressure, etc.).
Locally, the source rock can be slightly mature without expulsion.
In this study case, it is unlikely that zones with expulsion lower than 0.4 Gkg / km² (~ 3.1 Mbble / km²) significantly contribute to an active petroleum system.
To convert HC mass (Gkg) in equivalent barrels of oil (Million bble), multiply values by about 8 (average oil density estimated at 810 kg/m³).

Strong expulsion occurred in zones 3, 5, and 6, in the slope and the platform margin, where the expelled quantity exceeds 1000 Gkg/km². Expulsion is also significant in Zone 4. Elsewhere expulsion is very limited and cannot contribute significantly to HC accumulations (except locally in salt mini-basin of Zone 2).

TITHONIAN SR

%

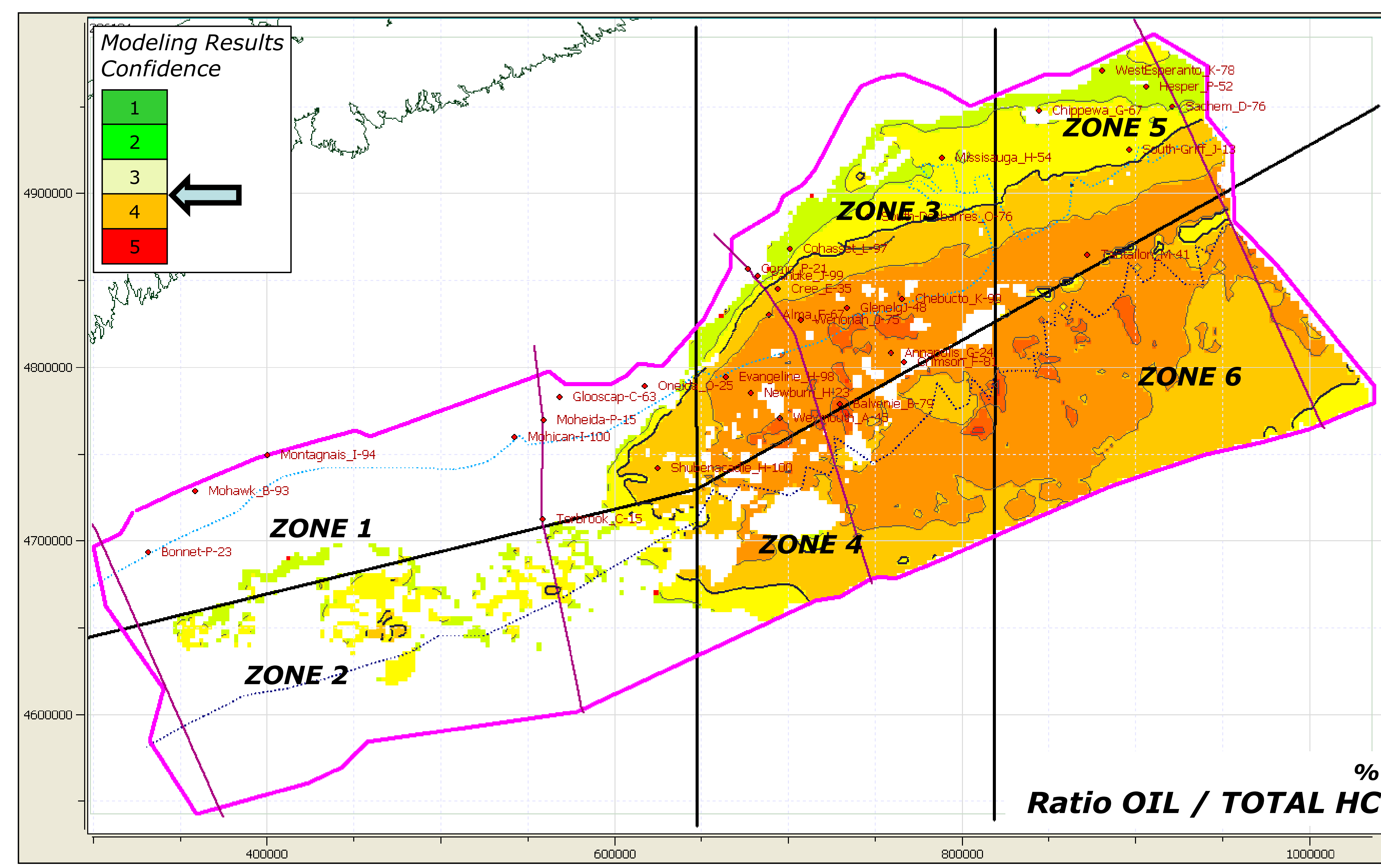
OIL mass fraction

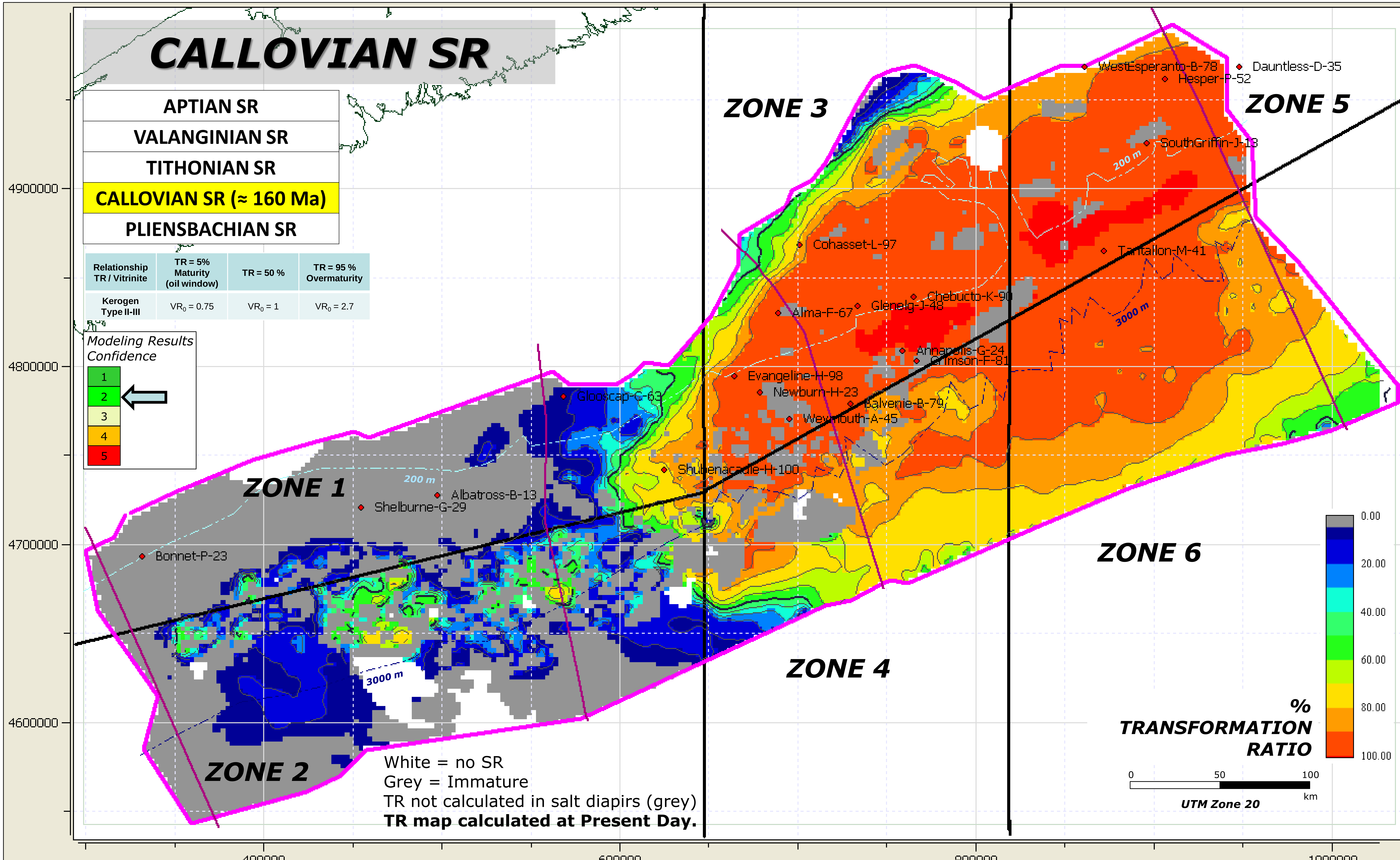


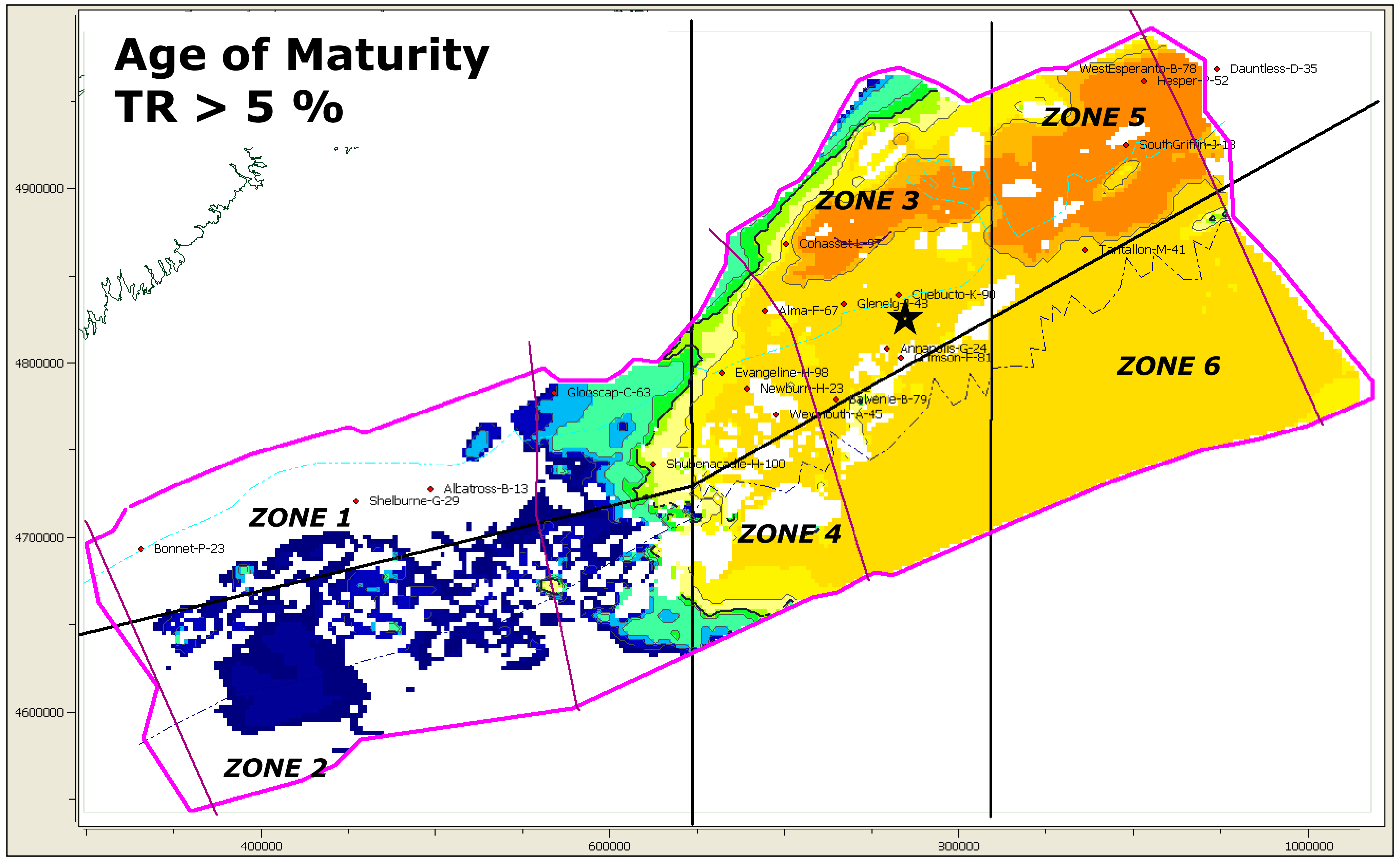
OIL /TOTAL HC Ratio Map at Present Day (in percent)

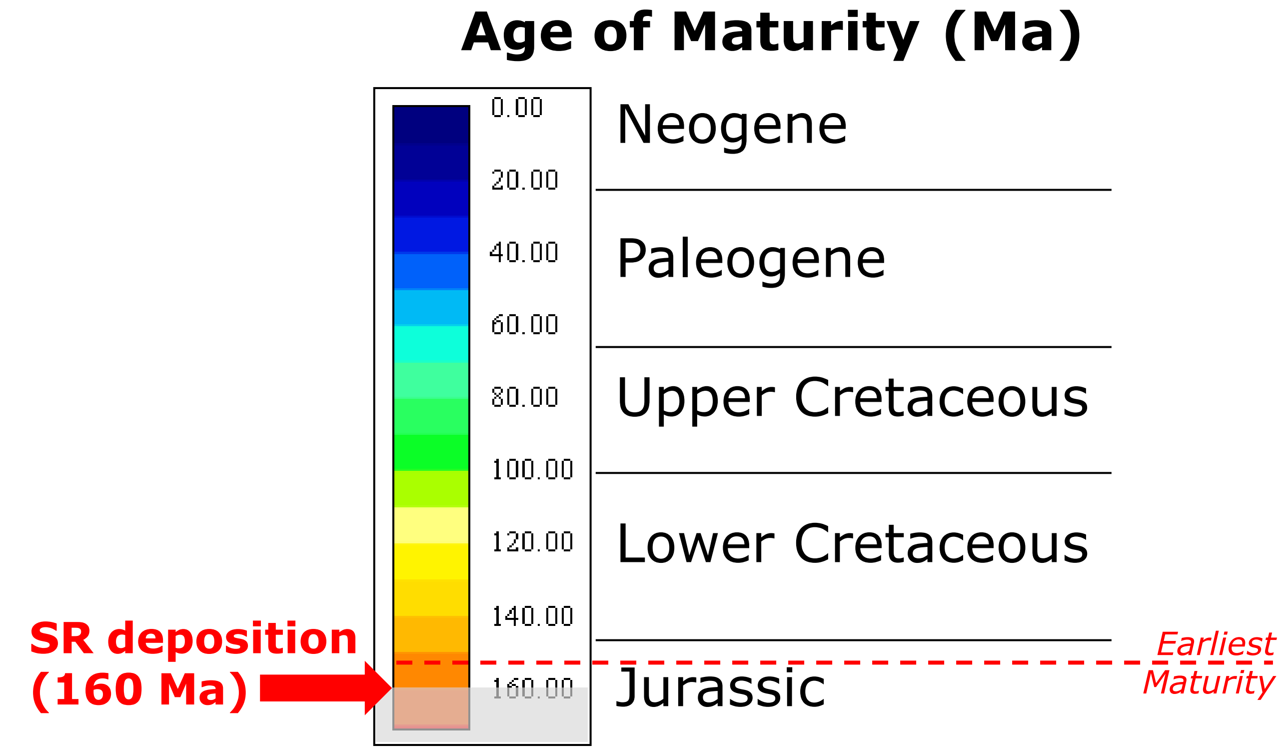
The map gives the fraction of oil expelled by the source rock through time:
ratio = mass of expelled oil / total mass of expelled HC.
This ratio takes into account secondary cracking of heavy HC occurring within the source rock layer, before expulsion, but cannot be representative of the amount of oil in place if secondary cracking occurs within reservoir layers.

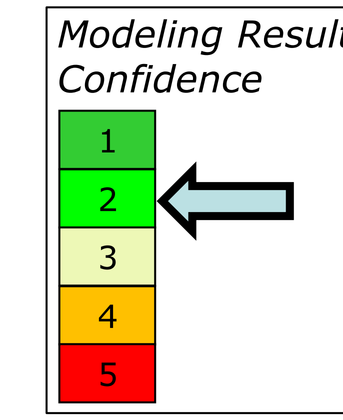
In the domain where the source rock is over mature the oil mass fraction is lower than 40% and even 30% locally.
On the contrary in the domain where the maturity of the source rock is less advanced the oil mass fraction is higher and can reach values greater than 60% locally.




CALLOVIAN SR
APTIAN SR
VALANGINIAN SR
TITHONIAN SR
CALLOVIAN SR (≈ 160 Ma)
PLIENSBACHIAN SR
Relationship TR / Vitrinite
TR = 5% Maturity (oil window)
TR = 50 %
TR = 95 % Overmaturity
Kerogen Type II-III
VR0 = 0.75
VR0 = 1
VR0 = 2.7
Modeling Results Confidence
1
2
3
4
5
ZONE 1
ZONE 2
ZONE 3
ZONE 4
ZONE 5
ZONE 6
WestEsperanto-B-78
Dauntless-D-35
Hesper-P-52
SouthGriffin-J-13
Cohasset-L-97
Tantallon-M-41
Chebucto-K-90
Glenelg-J-48
Alma-F-67
Annapolis-G-24
Crimson-F-81
Evangeline-H-98
Newburn-H-23
Balvenie-B-79
Weymouth-A-45
Glooscap-C-63
Shubenacadie-H-100
Albatross-B-13
Shelburne-G-29
Bonnet-P-23
200 m
3000 m
White = no SR
Grey = Immature
TR not calculated in salt diapirs (grey)
TR map calculated at Present Day.
% TRANSFORMATION RATIO
0.00
20.00
40.00
60.00
80.00
100.00
0
50
100
km
UTM Zone 20
4900000
4800000
4700000
4600000
400000
600000
800000
1000000



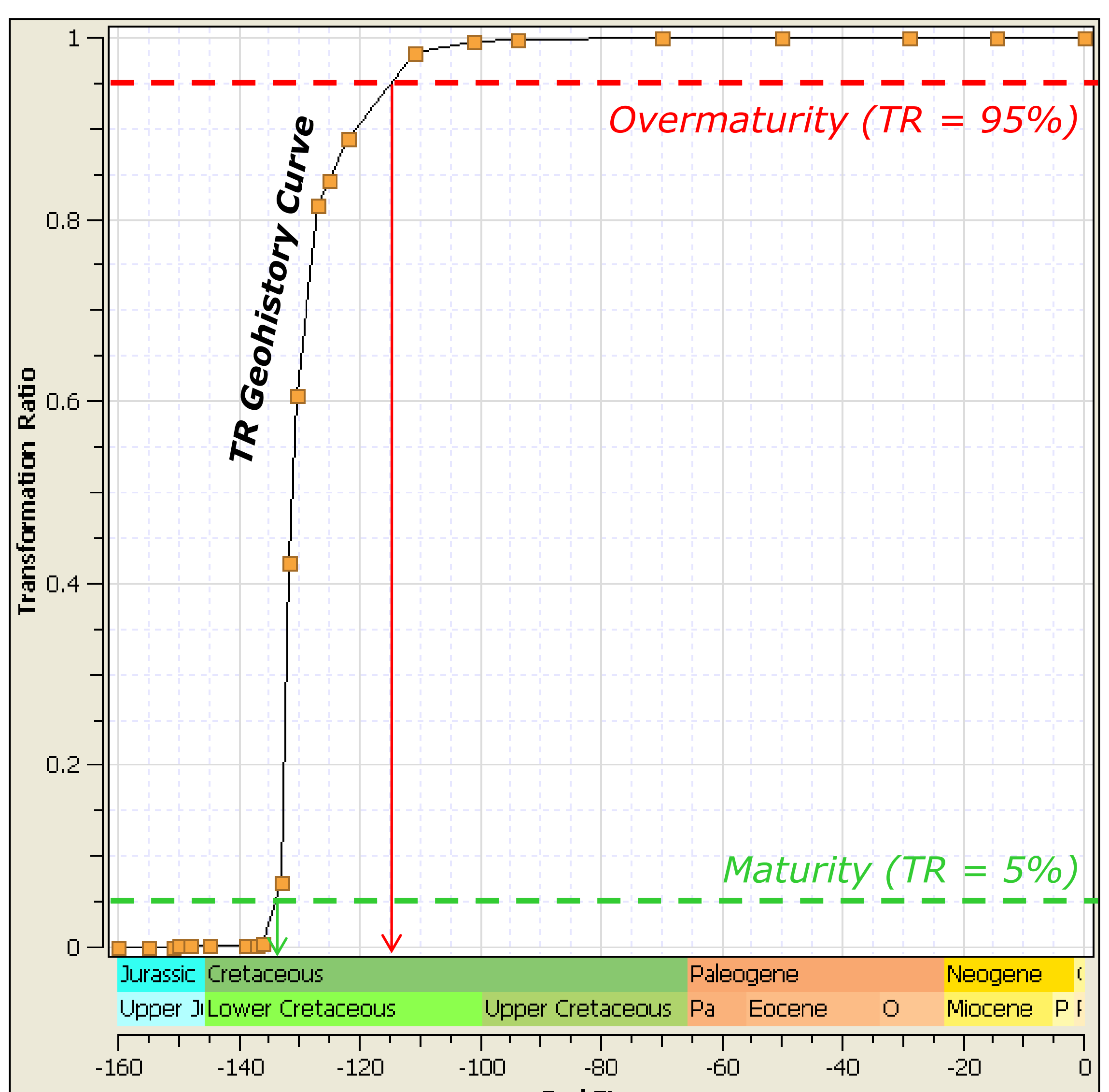




Age of maturity and of over-maturity (in Million Years)

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, 95% of Transformation Ratio for over-maturity.
Maturation of the Callovian SR started during late Jurassic or early Lower Cretaceous in zones 3, 4, 5 and 6. In the eastern part of zones 1 and 2 the maturity occurred latter (Upper Cretaceous). In the rest of zones 1 and 2 the maturity began during Paleogene or Neogene times.
The Callovian SR reached the over-maturity level early in the deepest part of the depression (about 130 M years ago) in zones 3, 5 and locally in Zone 6. On the platform of zones 3 and 5, the TR exceeds 95% since the Uppermost Cretaceous.

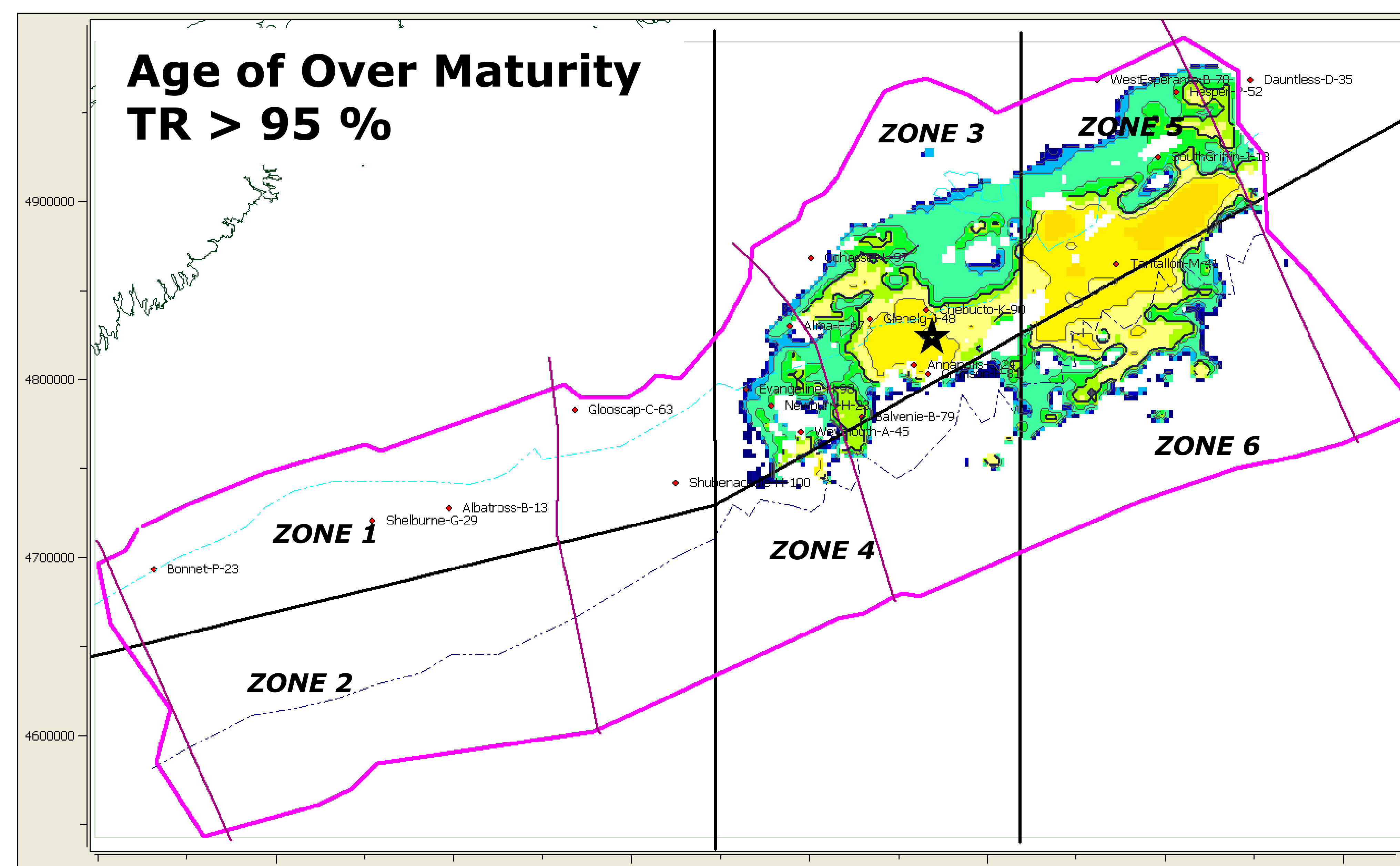
CALLOVIAN SR

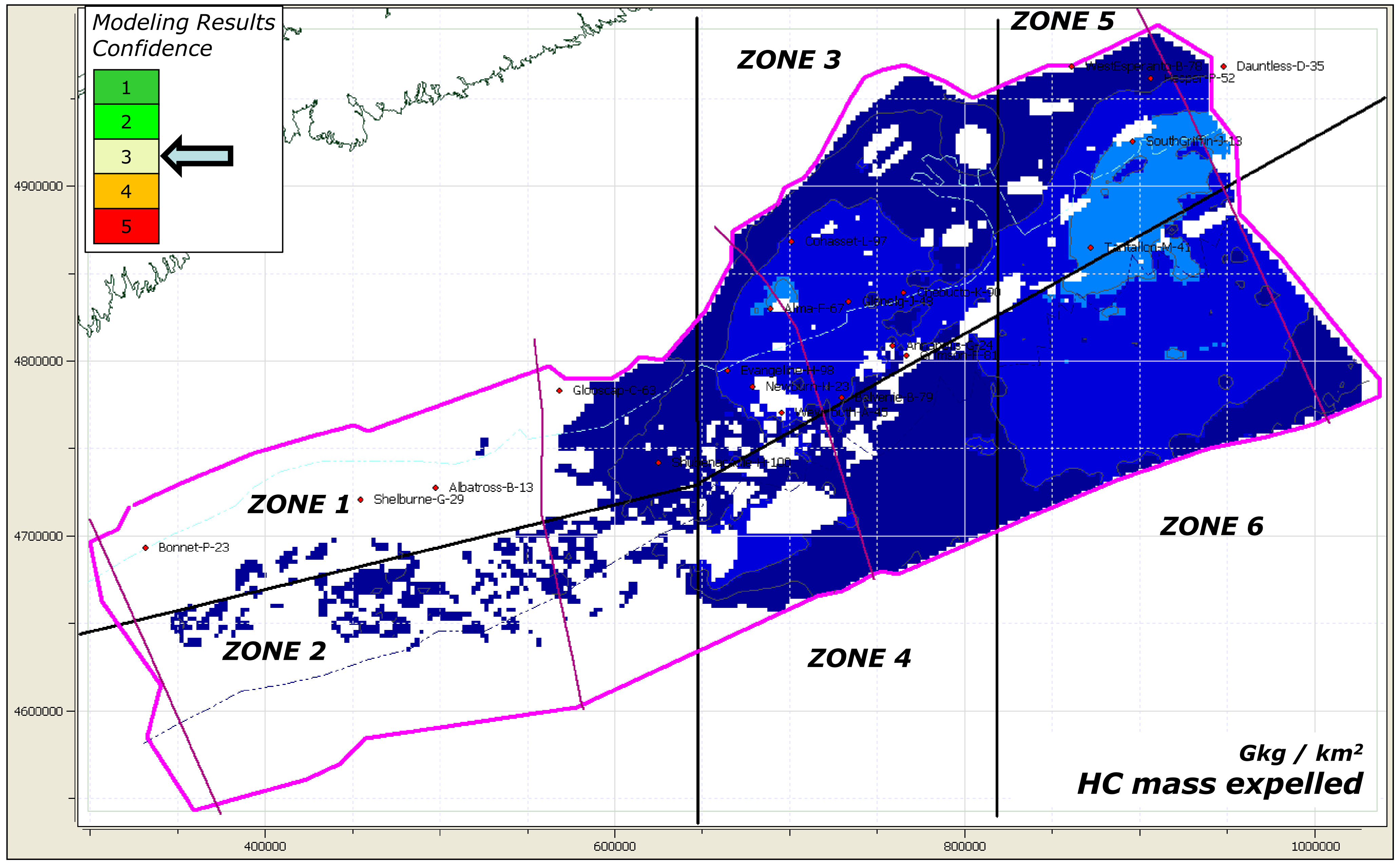


Evolution of the Maturity in the deep mini-basin between Chebucto and Annapolis

The graph indicates the evolution of the Transformation Ratio through time at the deepest point of the mini-basin located between Chebucto and Annapolis (black star on maps, Zone 3, south of the shelf break). This is one of the most mature zone in the Basin.

At this location, the Tithonian SR experienced 1 main phase of maturation related to the Lower Cretaceous rapid burial episode: between 135 and 115 Ma. The decrease of the maturation speed after 115 Ma is more related to a specificity of the kerogen kinetic than to a decrease of the burial rate.





Gkg / km²

1 Gkg = 10^9 kg = 1 Million T

~ 7.8 Mbble

HC mass expelled

0.2000	*Limited expulsion*
0.4000	
0.6000	*Significant expulsion*
0.8000	
1.0000	*Very strong expulsion*
1.2000	

Expulsion Map at Present Day (by square kilometer)

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 0.4 Gkg / km² (~ 3.1 Mbble / km²) significantly contribute to an active petroleum system.
To convert HC mass (Gkg) in equivalent barrels of oil (Million bble), multiply values by about 8 (average oil density estimated at 810 kg/m³).

Expulsion for the Callovian Source Rock exits in zones 3, 4, 5 and 6 but remained limited in intensity. Even in the area where expulsion is maximum (in the eastern part of Zone 5) its magnitude is less than 400 Gkg / km². This source Rock do not significantly contributes to a petroleum system.

CALLOVIAN SR

%

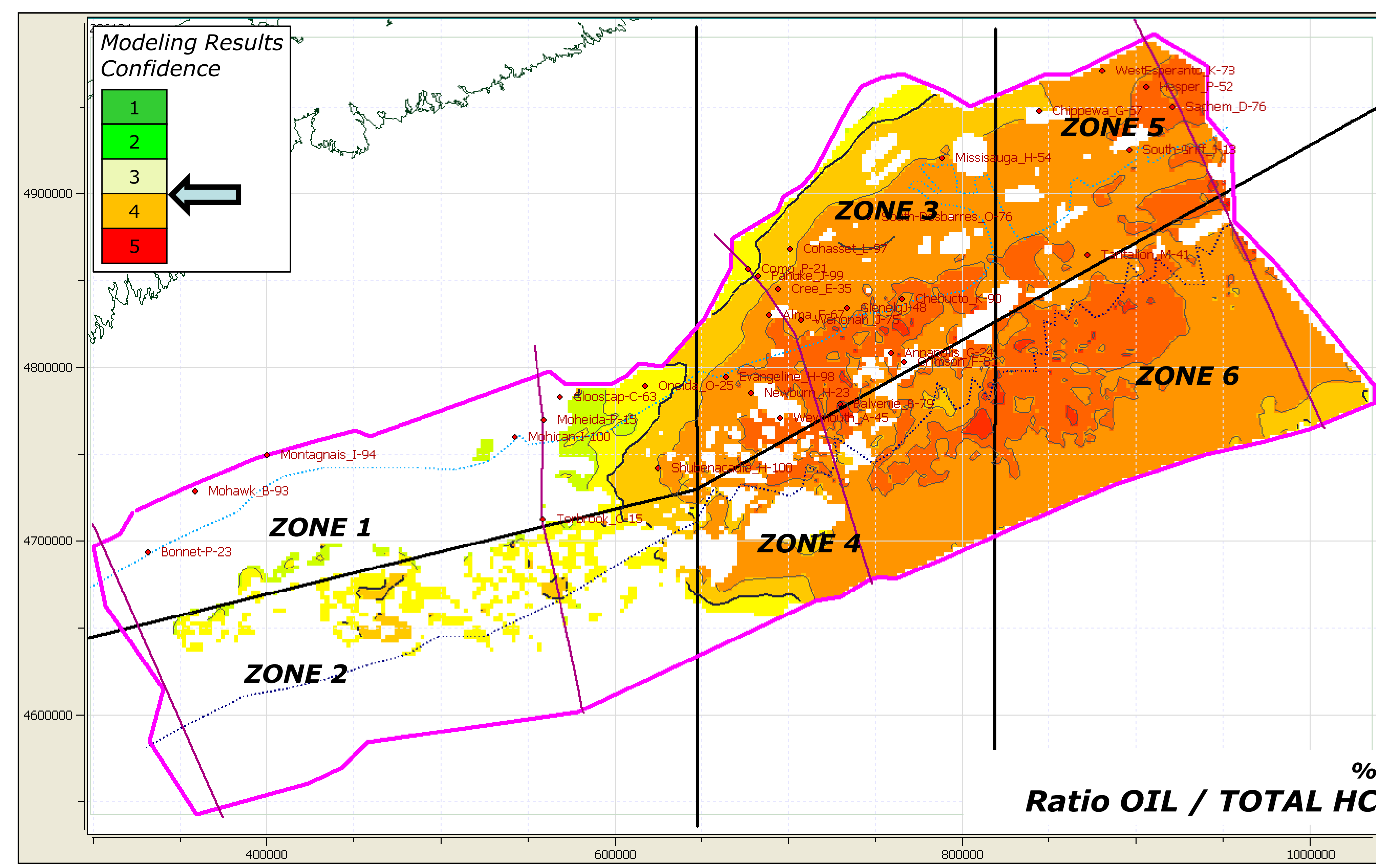
OIL mass fraction

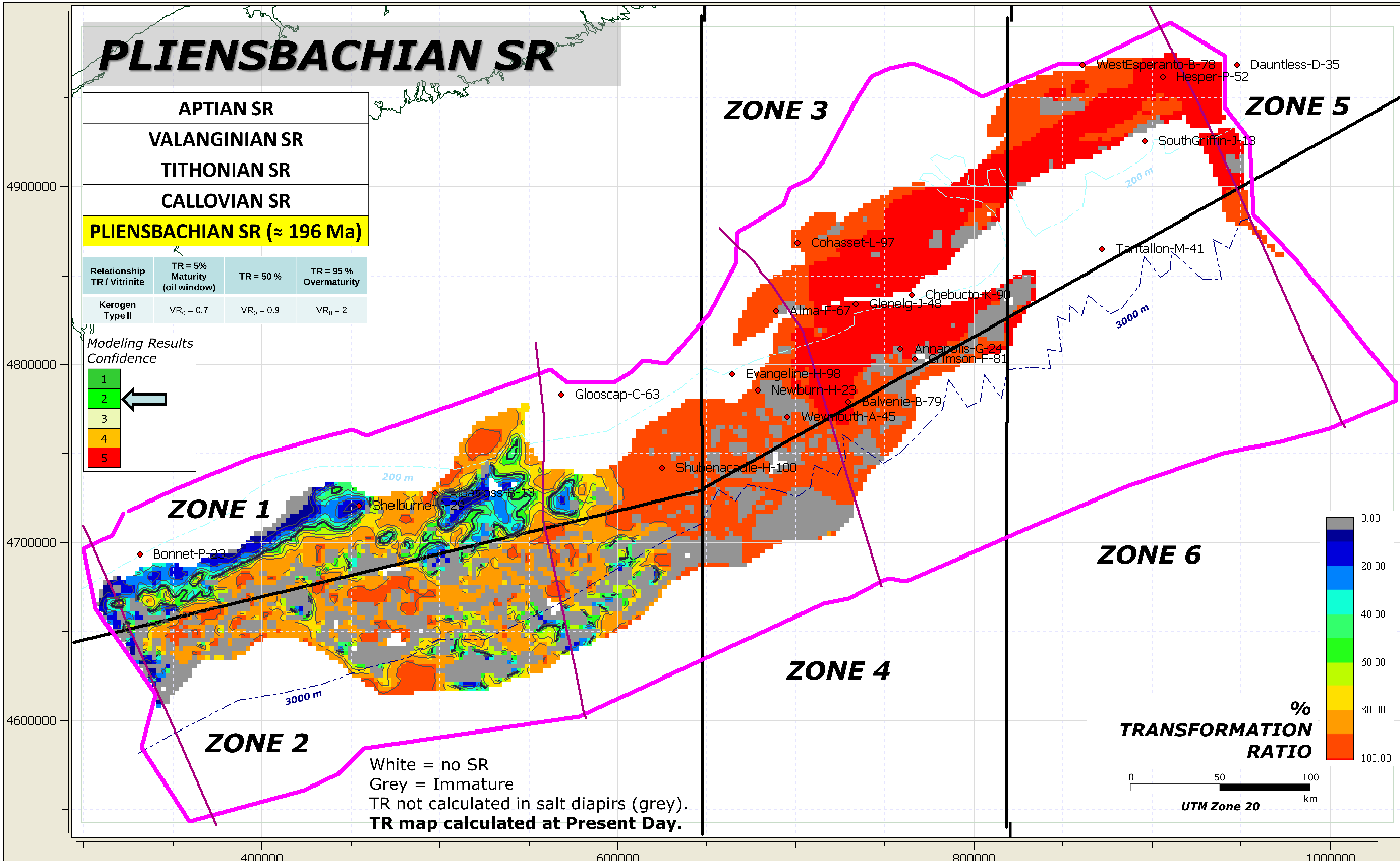
0.00
20.00
40.00
60.00
80.00
100.00

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

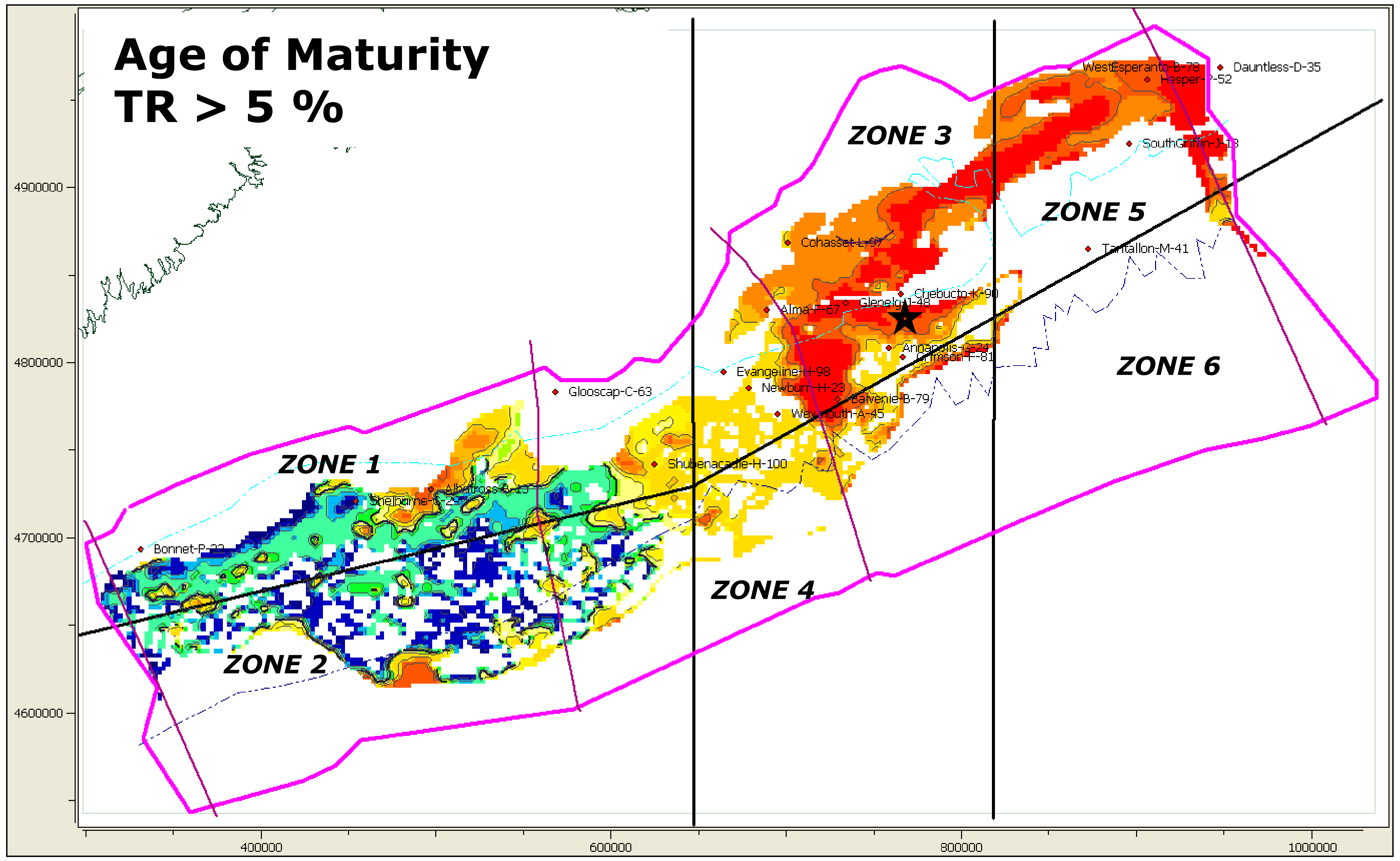
The map gives the fraction of oil expelled by the source rock through time:
ratio = mass of expelled oil / total mass of expelled HC.
This ratio takes into account secondary cracking of heavy HC occurring within the source rock layer, before expulsion, but cannot be representative of the amount of oil in place if secondary cracking occurs within reservoir layers.

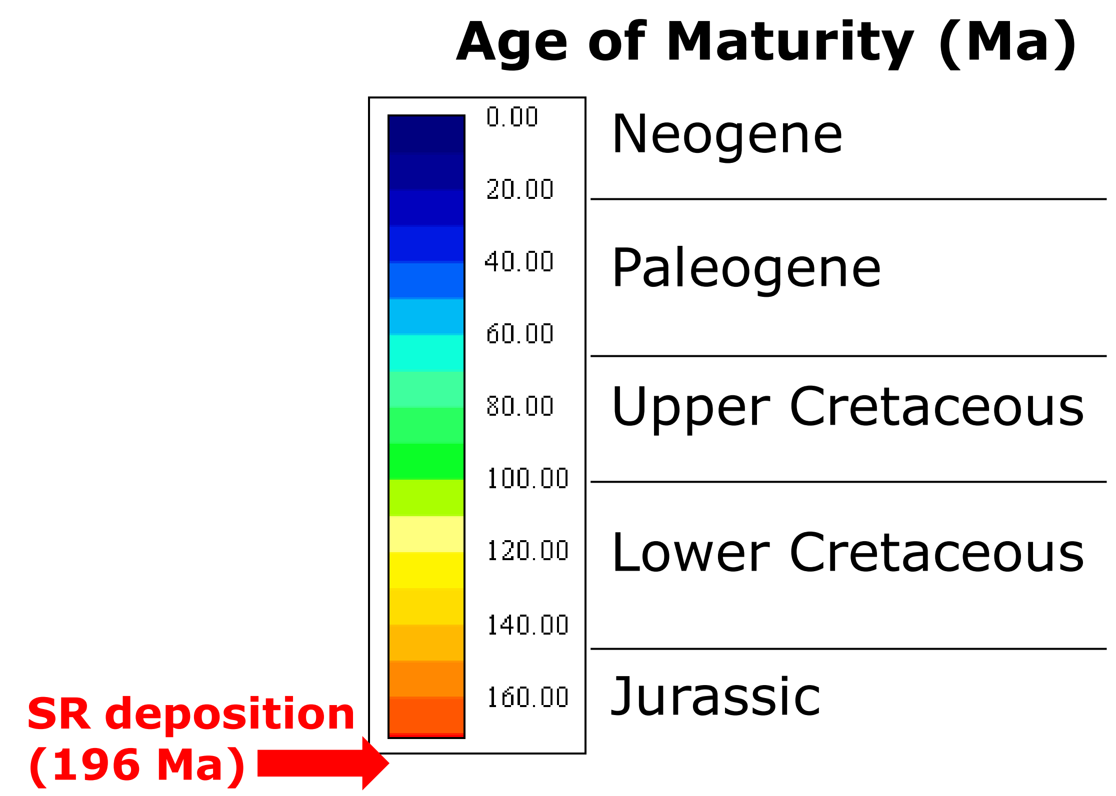
The amount of oil fraction is predominantly between 20% and 40% in the zones 3, 4, 5 and 6. Locally, the amount of oil fraction may even be lower (around 10%) in the deepest part of the basin where secondary cracking occurs in the Source Rock.
In the zones 1 and 2, where the maturity is lower, the amount of oil fraction is higher and reaches values of 60% to 70 %.

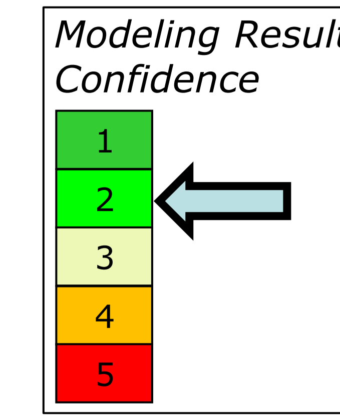




3D Maturity / Expulsion Modeling – PLIENSBACHIAN SR – Transformation Ratio Map





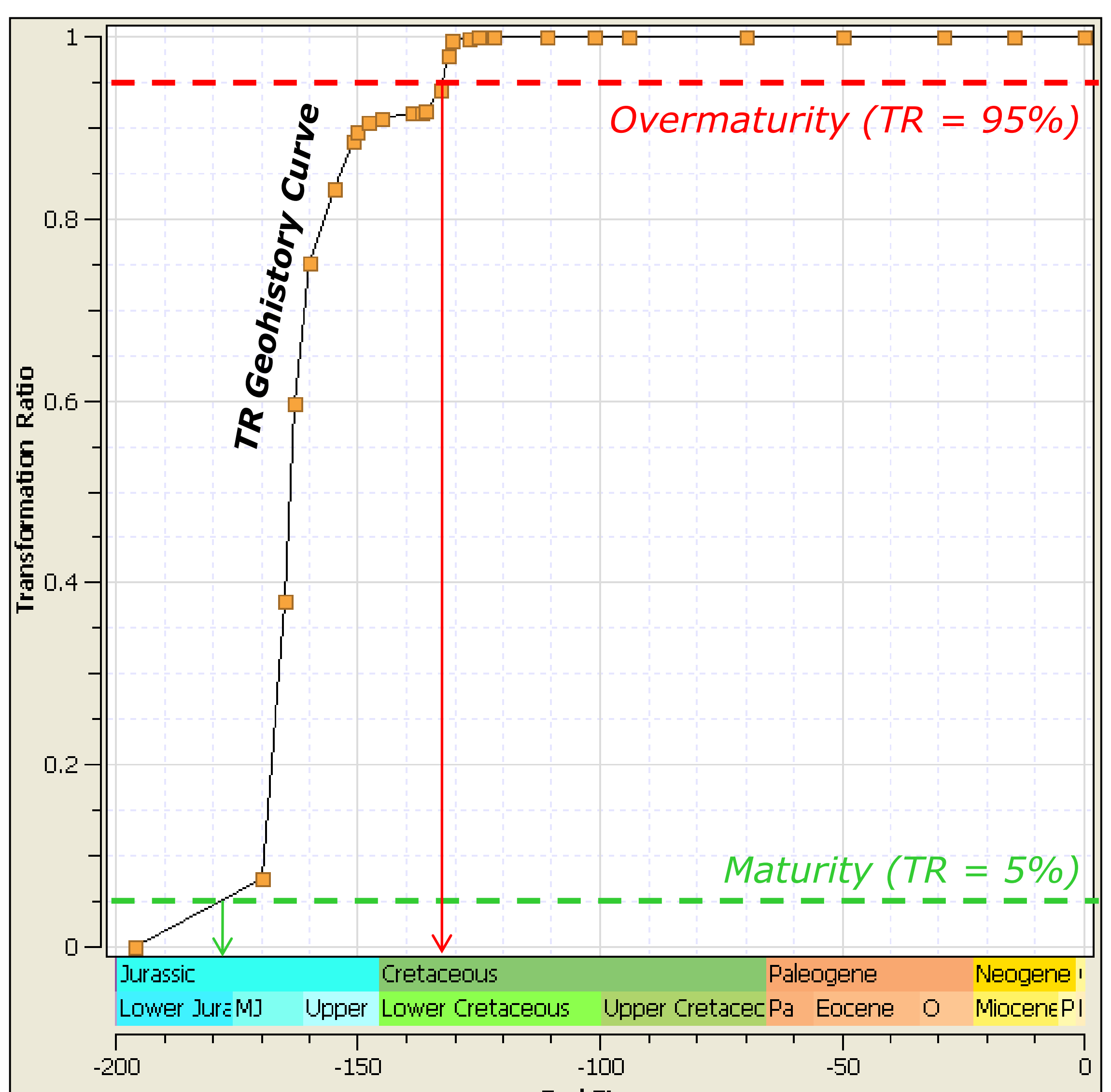


Age of maturity and of over-maturity (in Million Years)

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, 95% of Transformation Ratio for over-maturity.

Maturation of the Pliensbachian SR started early at Jurassic times north east of Section NS1600 (zones 3 and 5). In the westernmost part of Zone 3, in Zone 4, and in the deepest parts of zones 1 and 2 (Glooscap and mini-basins), the maturation started during the Lower Cretaceous. Globally the maturation started much latter in zones 1 and 2, during Paleogene times.
The over-maturity level was reached very early in zones 3, 4, and 5 (Lower Cretaceous or Jurassic).

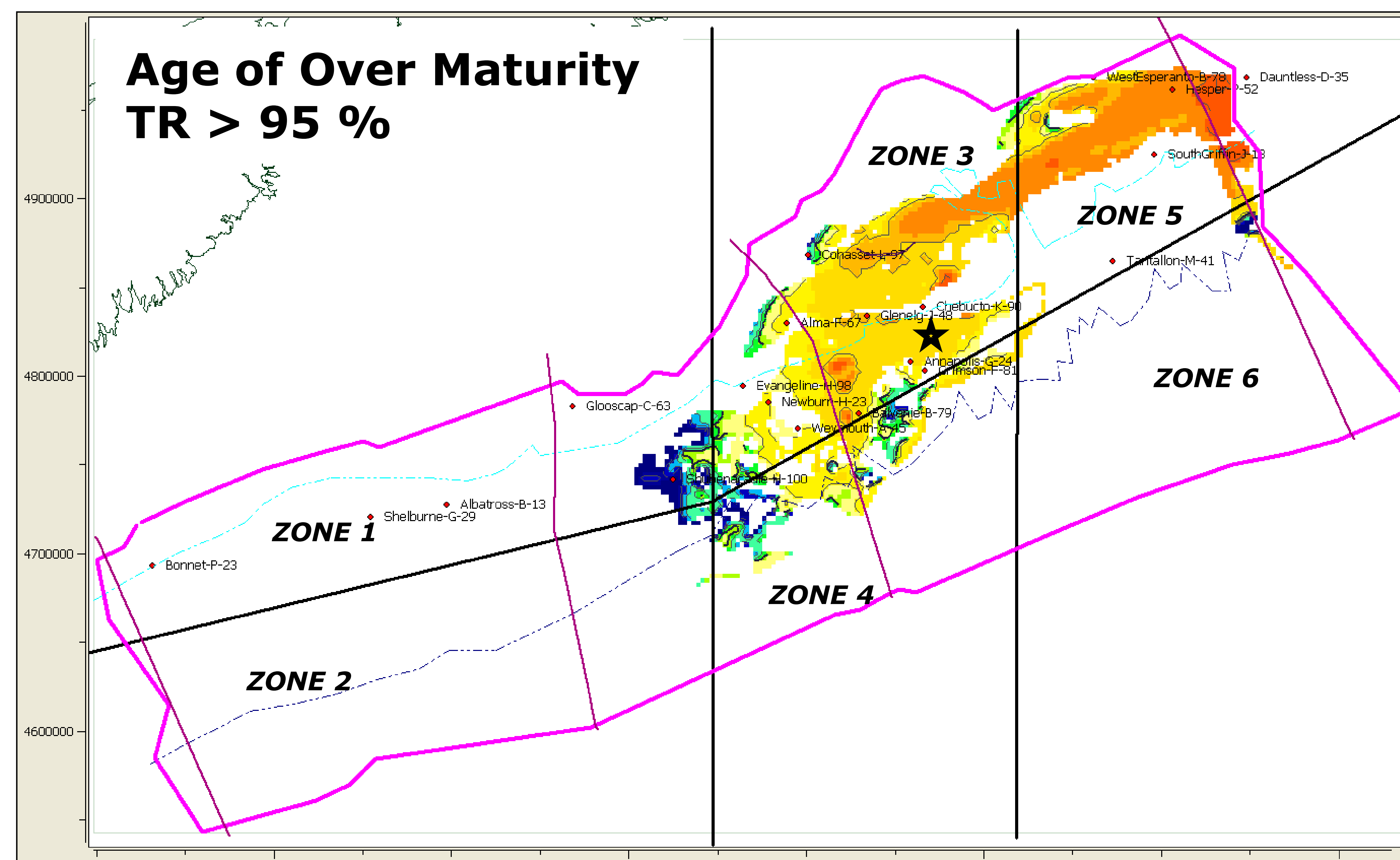
PLIENSBACHIAN SR

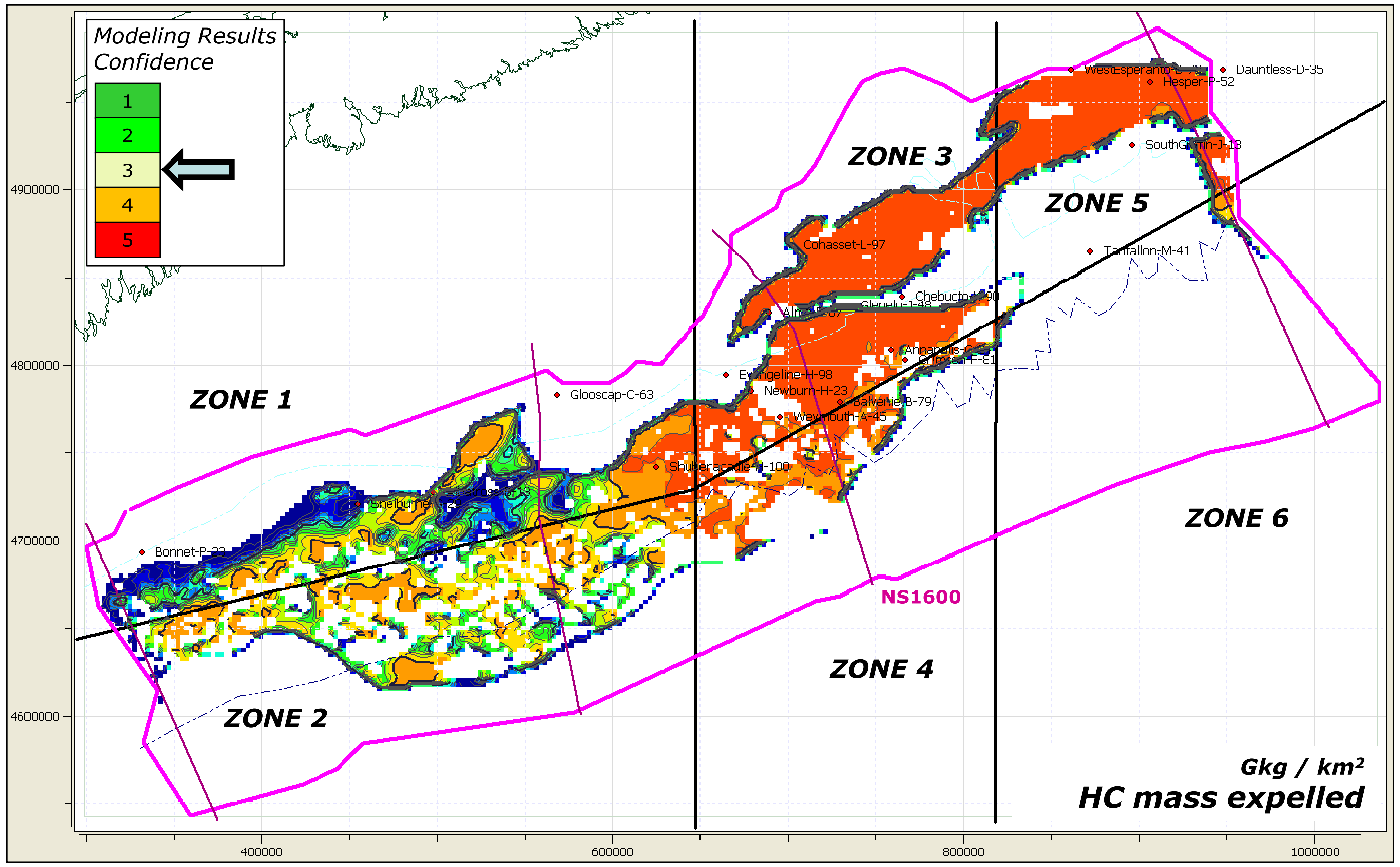


Evolution of the Maturity in the deep mini-basin between Chebucto and Annapolis

The graph indicates the evolution of the Transformation Ratio through time at the deepest point of the mini-basin located between Chebucto and Annapolis (black star on maps, Zone 3, south of the shelf break). This is one of the most mature zone in the Basin.

At this location, the Pliensbachian SR experienced 2 main phases of maturation: between 170 and 160 Ma; around 130 Ma (Lower Cretaceous rapid burial episode).



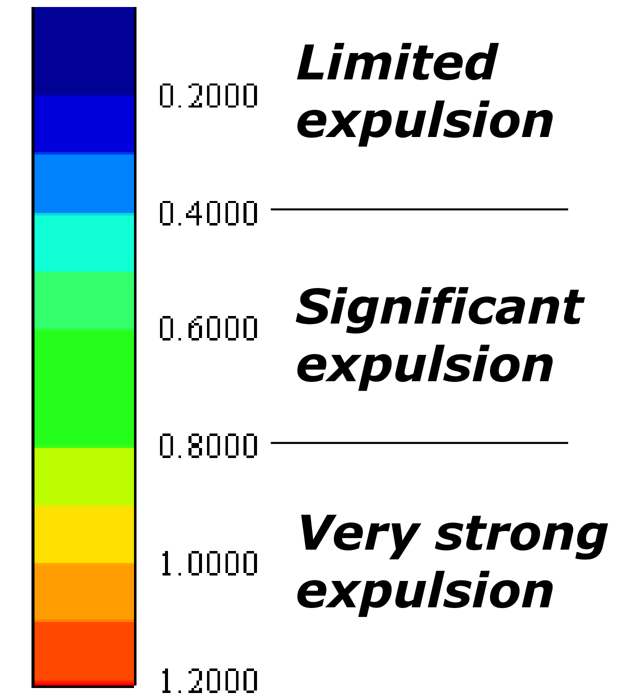


Gkg / km²

1 Gkg = 10^9 kg = 1 Million T

~ 7.8 Mbble

HC mass expelled



Expulsion Map at Present Day (by square kilometer)

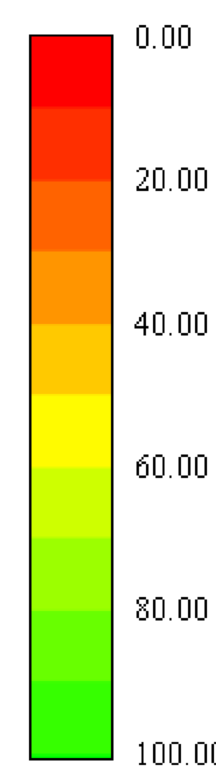
The map gives HC mass expelled through time (cumulated mass).
HC mass expelled = oil mass expelled + gas mass expelled
Expulsion process corresponds to primary migration of HC out of SR layers.
Expelled volumes are smaller than generated volumes and depend on petrophysical properties of source rocks (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 (~ 3.1 Mbble / km²) significantly contribute to an active petroleum system.
To convert HC mass (Gkg) in equivalent barrels of oil (Million bble), multiply values by about 8 (average oil density estimated at 810 kg/m³).

For the Pliensbachian Source Rock expulsion mainly occurs in zones 3 and 5 and in the north of zone 4 where the quantity exceeds 1200 Gkg/km². Expulsion is also very important at east of zone 1 and locally in scattered area of zones 1 and 2 where it can exceed 1000 Gkg/km².

PLIENSBACHIAN SR

%

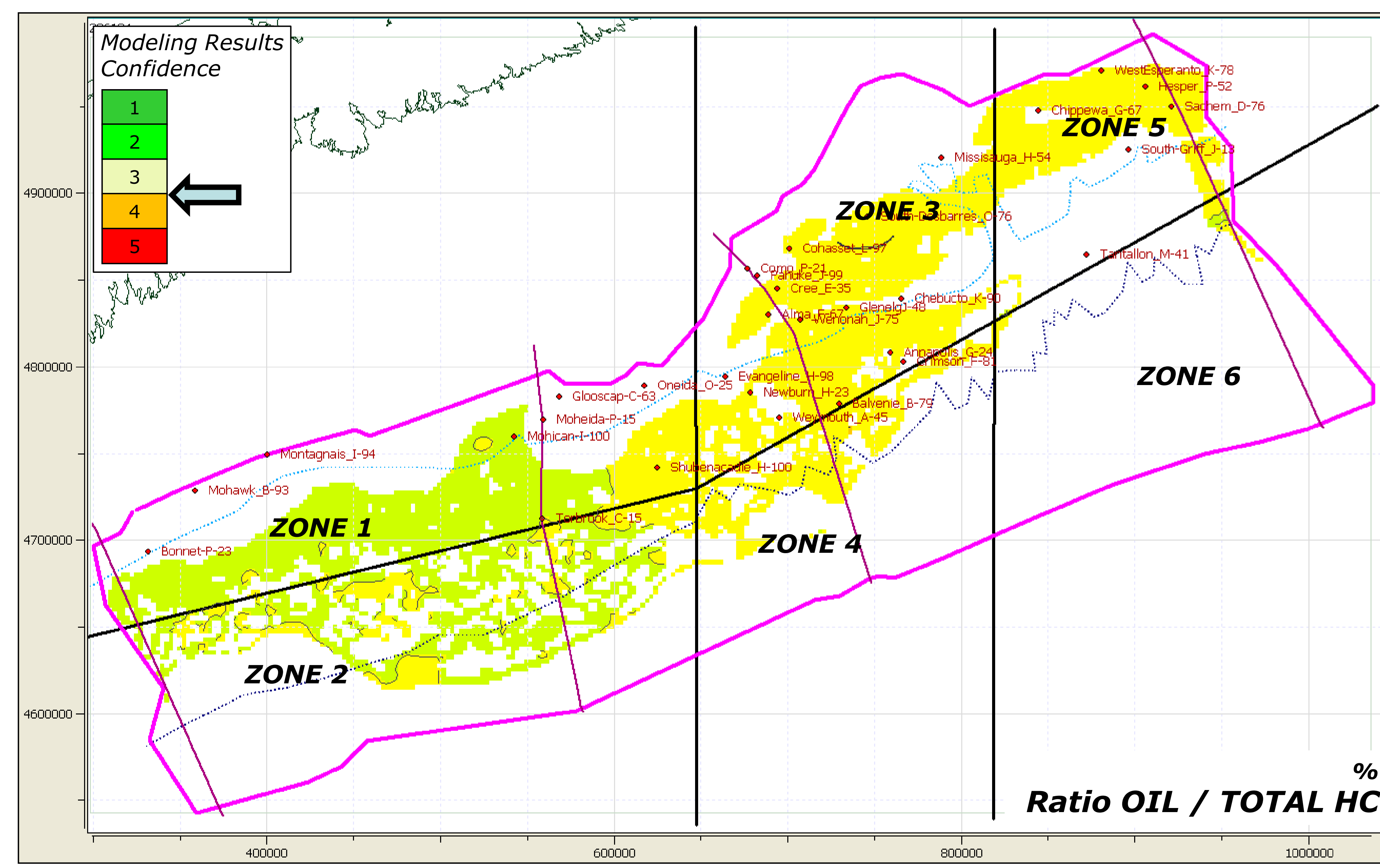
OIL mass fraction



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 takes into account secondary cracking of heavy HC occurring within the source rock layer, before expulsion, but cannot be representative of the amount of oil in place if secondary cracking occurs within reservoir layers.

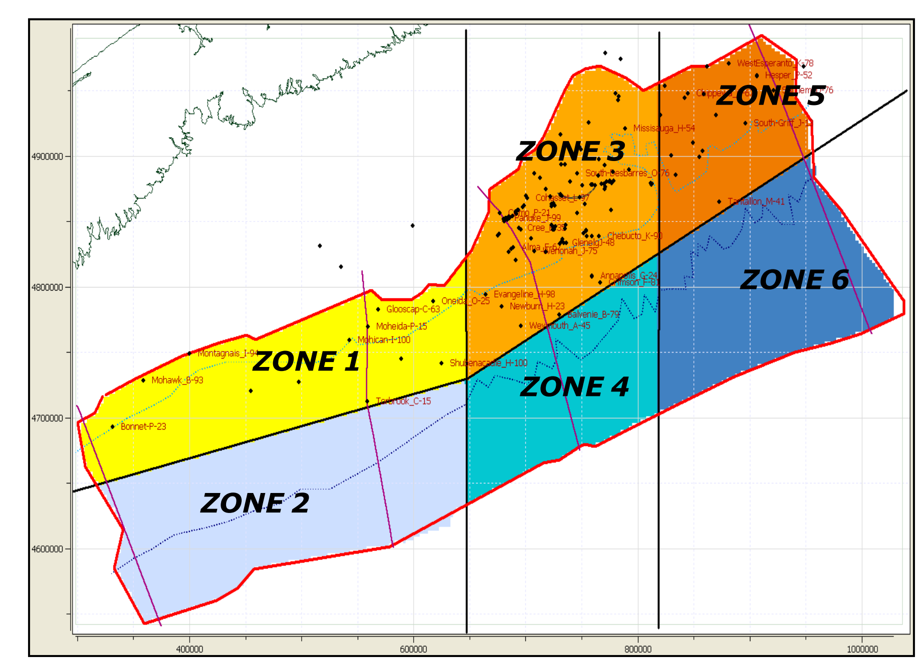
The Pliensbachian SR expelled more oil than gas. It is a oil prone SR.
The oil mass fraction is close to 60% at the east of the study domain and is even higher, close to 70% at the west of the study domain.



		APTIAN SR Type III	VALANGINIAN SR Type III	TITHONIAN SR Type II-III	CALLOVIAN SR Type II-III	PLIENSBACHIAN SR Type II	WHOLE SR HC mass expelled (in Gkg Or MT)	WHOLE SR HC volume expelled (in Tcf for gas; in Billion bbl for oil and oil equivalent)	WHOLE SR GORfeed expelled (in kg/kg)	WHOLE SR GOR expelled (in scf/stb)
ZONE 1	GAS expelled (in Gkg)	8	33	810	248	3138	4200	**230**	0.7	**4600**
	OIL expelled (in Gkg)	4	10	693	212	5213	6100	**50**		
	TOTAL HC expelled (in Gkg) and oil equivalent	12	43	1504	460	8351	**10400**	**80**		
ZONE 2	GAS expelled (in Gkg)	0	35	671	163	3293	4200	**230**	0.7	**4600**
	OIL expelled (in Gkg)	0	11	768	160	5260	6200	**50**		
	TOTAL HC expelled (in Gkg) and oil equivalent	0	46	1439	323	8553	**10400**	**80**		
ZONE 3	GAS expelled (in Gkg)	733	4904	9277	2577	5719	23200	**1250**	1.5	**10400**
	OIL expelled (in Gkg)	294	841	5917	1404	7205	15700	**120**		
	TOTAL HC expelled (in Gkg) and oil equivalent	1026	5745	15194	3982	12924	**38900**	**300**		
ZONE 4	GAS expelled (in Gkg)	2	655	6767	1522	1714	10700	**580**	1.5	**9700**
	OIL expelled (in Gkg)	1	185	4289	783	2062	7300	**60**		
	TOTAL HC expelled (in Gkg) and oil equivalent	3	840	11056	2305	3776	**18000**	**140**		
ZONE 5	GAS expelled (in Gkg)	23	1858	5314	2115	2792	12100	**650**	1.3	**9300**
	OIL expelled (in Gkg)	14	527	4119	998	3563	9200	**70**		
	TOTAL HC expelled (in Gkg) and oil equivalent	37	2384	9433	3112	6355	**21300**	**170**		
ZONE 6	GAS expelled (in Gkg)	0	144	12957	3734	144	17000	**910**	1.7	**11400**
	OIL expelled (in Gkg)	0	46	8194	1743	177	10200	**80**		
	TOTAL HC expelled (in Gkg) and oil equivalent	0	190	21150	5477	320	**27100**	**210**		
WHOLE BASIN	GAS expelled (in Gkg)	800	7600	35800	10400	16800	71400			
	GAS expelled (in Tcf)	**40**	**410**	**1920**	**560**	**900**	**3840**			
	OIL expelled (in Gkg)	300	1600	24000	5300	23500	54700			
	OIL expelled (in Billion bbl)	**2**	**10**	**190**	**40**	**180**	**426**			
	TOTAL HC expelled (in Gkg)	1100	9200	59800	15700	40300	126100			
	TOTAL OIL EQUIVALENT expelled (in Billion bble)	**9**	**70**	**470**	**120**	**310**	**980**			
	GOR feed expelled (kg/kg)	2.7	4.8	1.5	2.0	0.7	1.3			
	GOR expelled (in scf/stb)	**17100**	**41000**	**10100**	**14000**	**5000**	**9000**			

Modeling Results Confidence

1
2
3
4
5

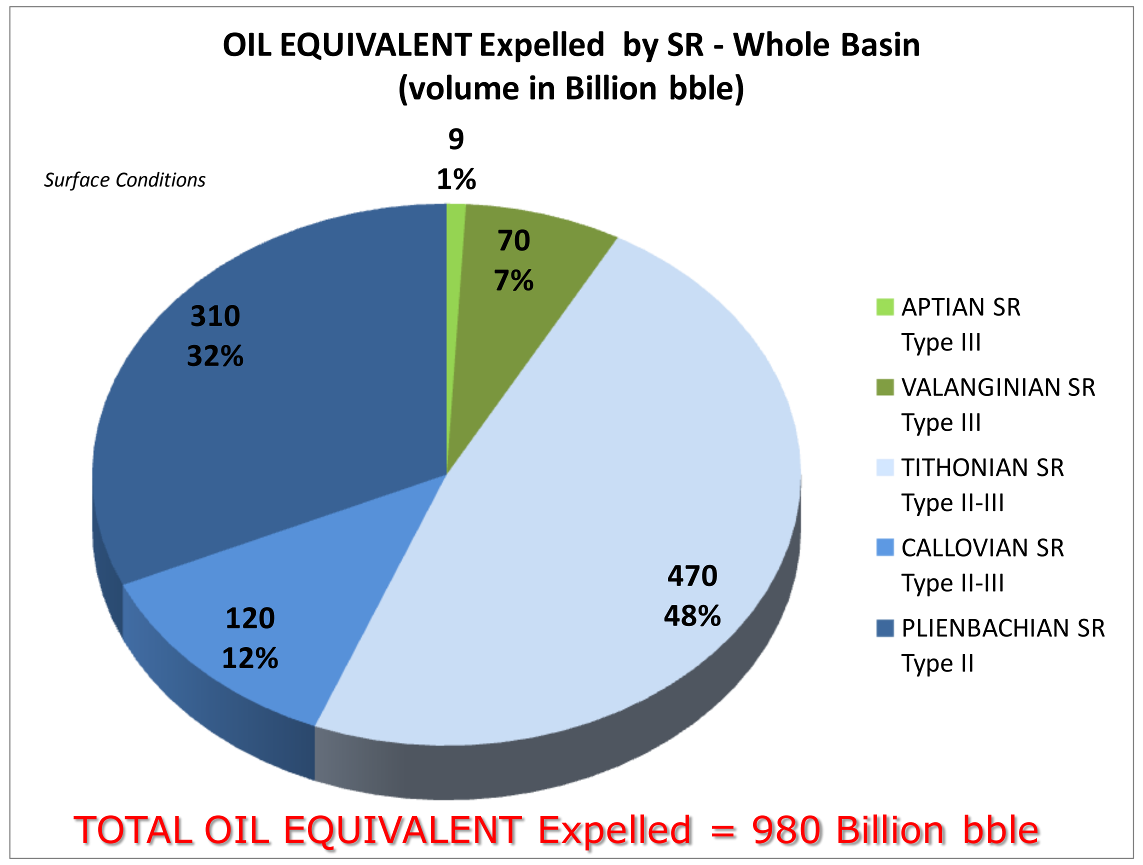


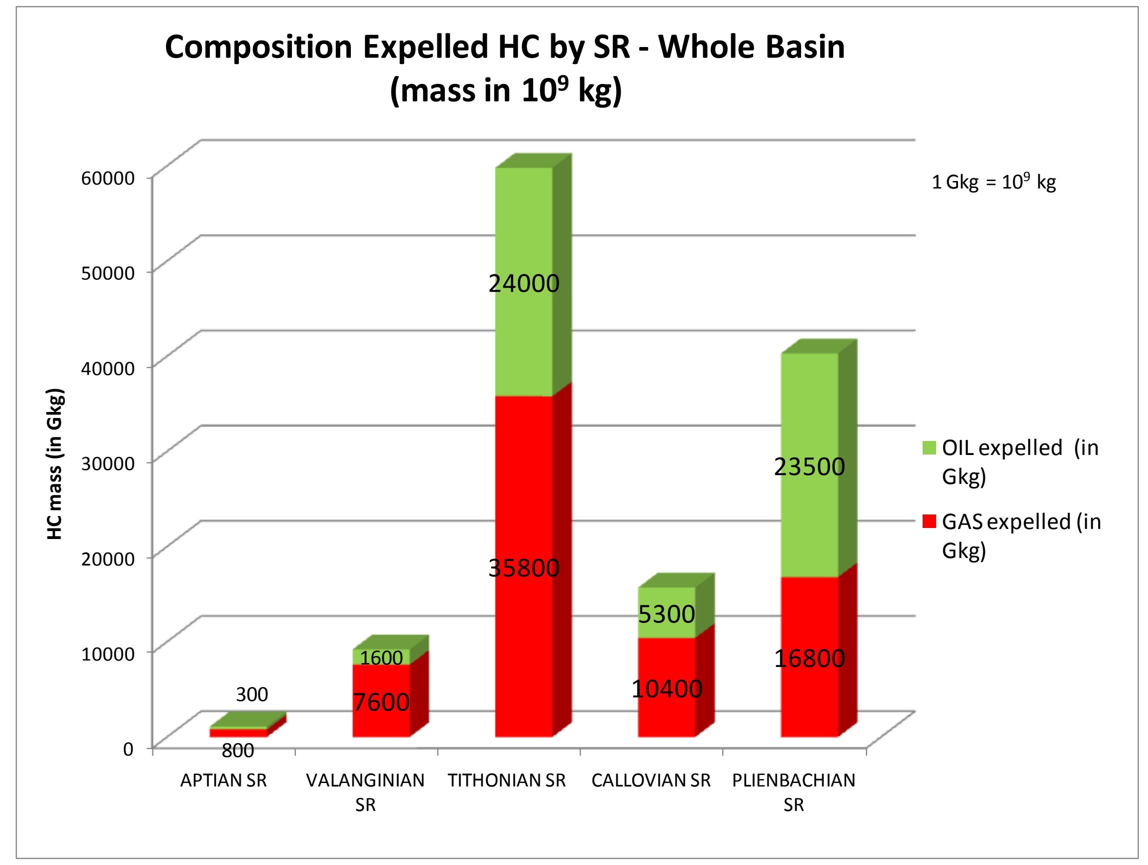
Expelled HC masses and volumes – By ZONE – By SOURCE ROCK (numerical table)

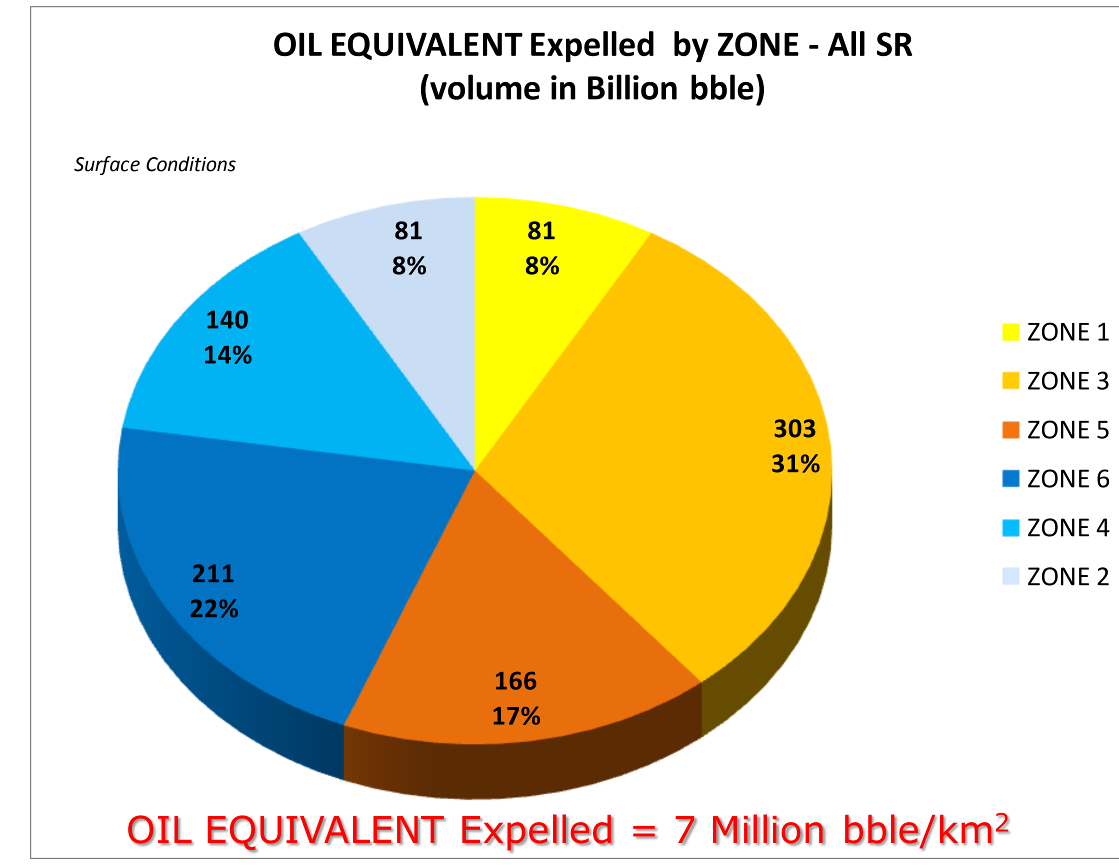
Amount of expelled HC are computed in mass and converted in volumes (surface conditions, d_{oil} = 807 kg/m³ d_{gas} = 0.657 kg/m³).
The model takes into account secondary cracking in source rock layers, before expulsion (but not secondary cracking that occurs later in reservoir layers). No threshold on expelled masses per km².

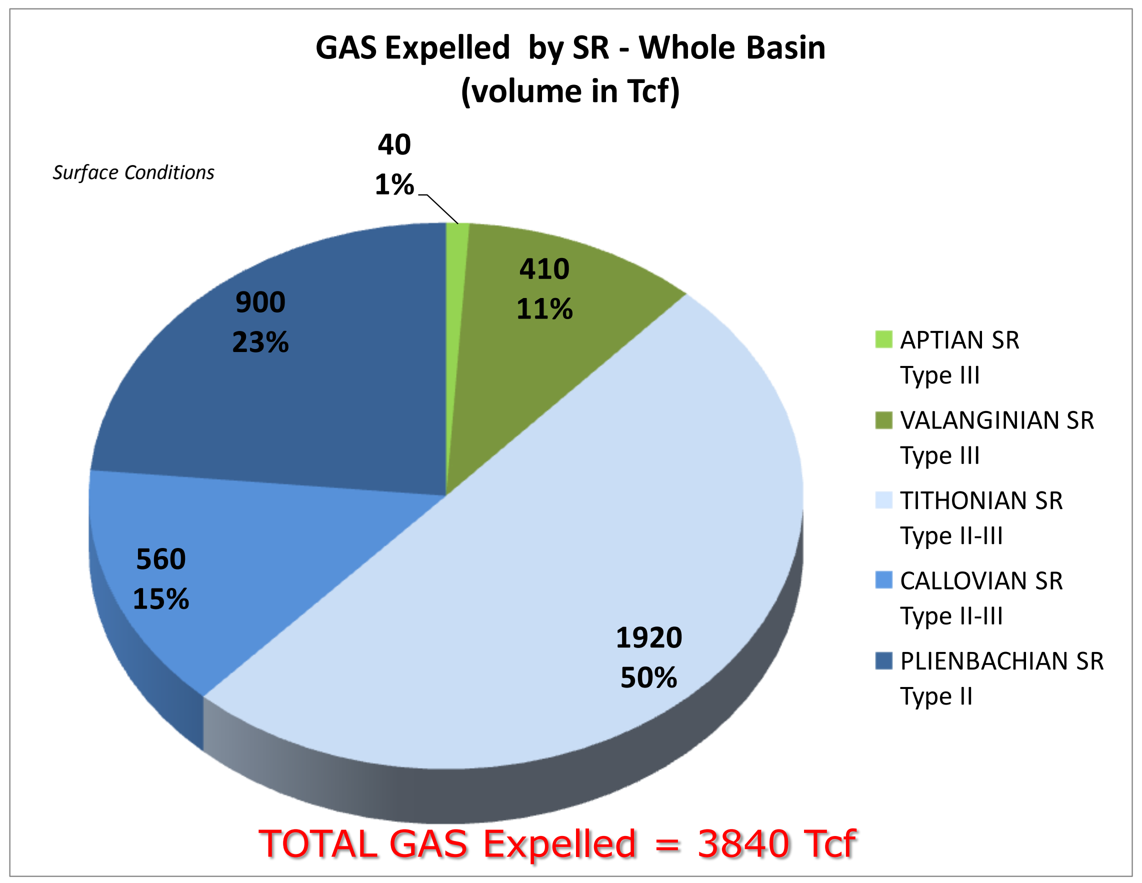
By SOURCE ROCK

By ZONE









Expelled HC masses and volumes (By Source Rock / By Zone)

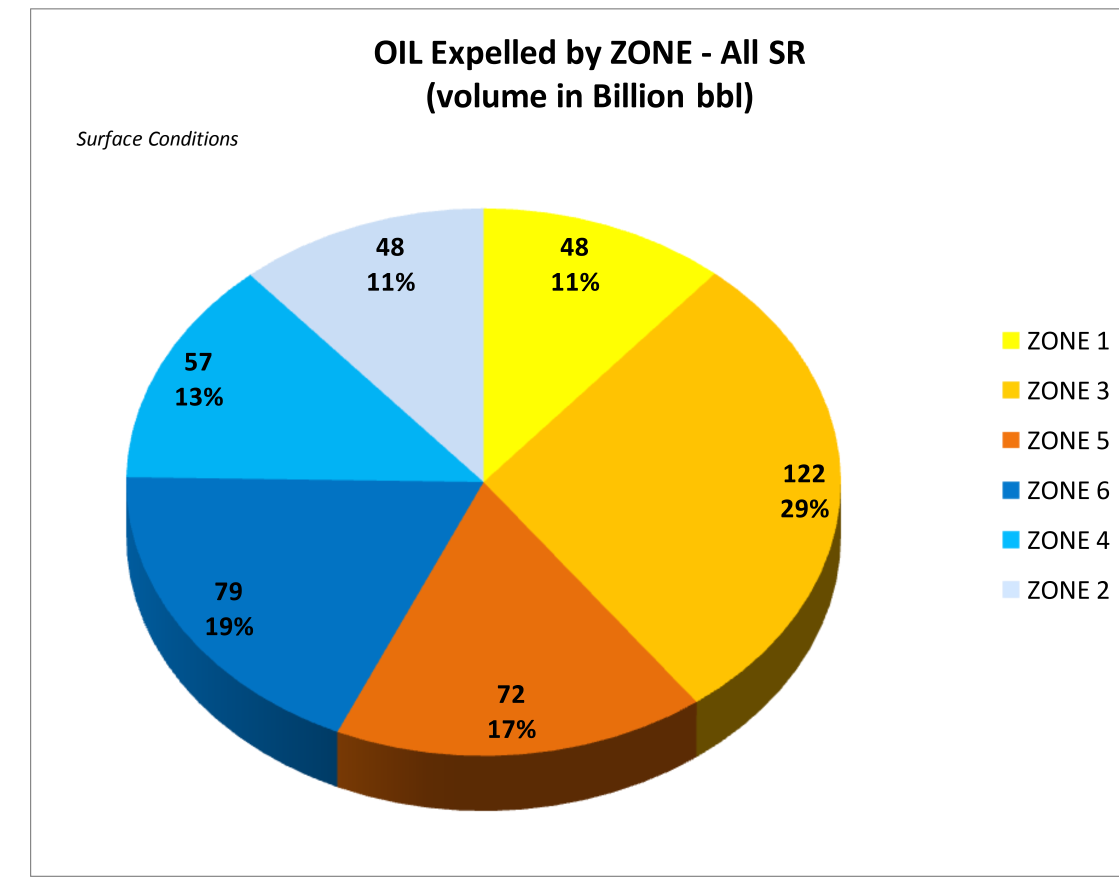
BY SOURCE ROCK

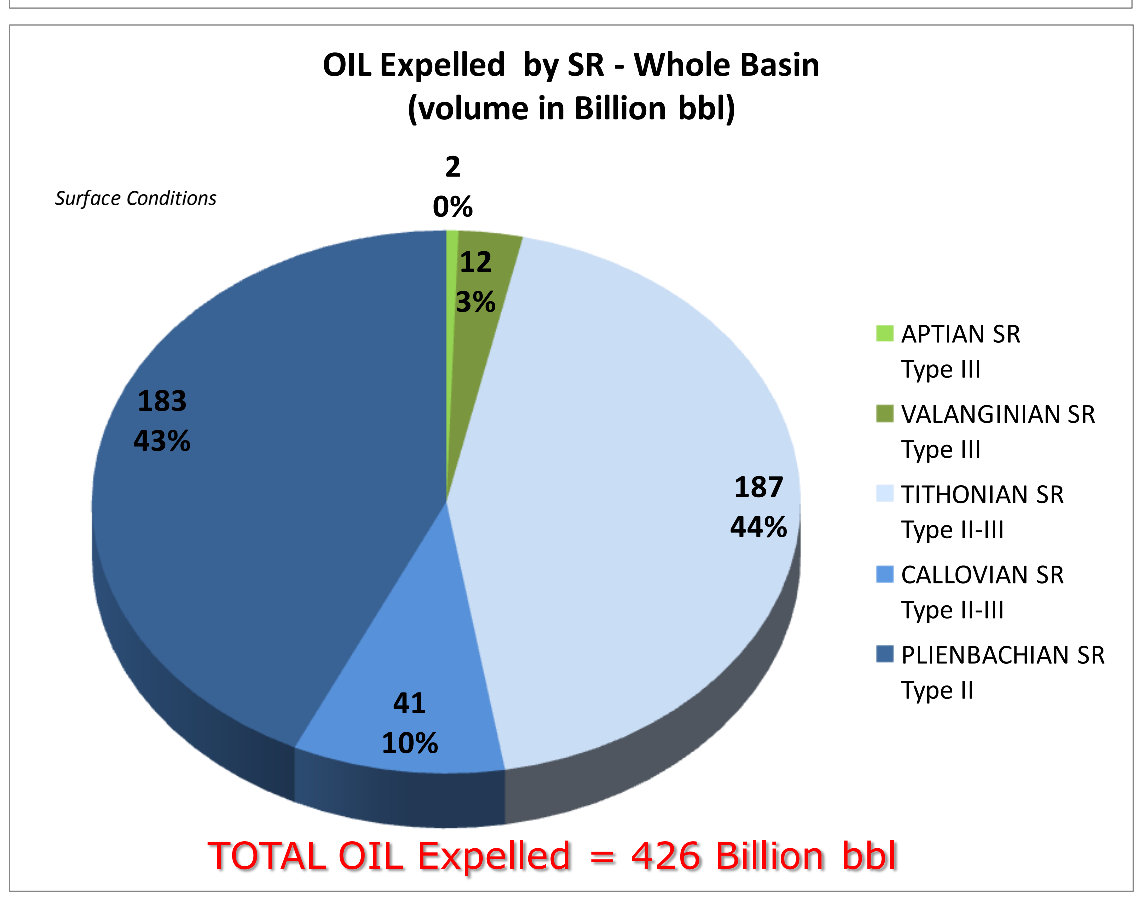
The main contributors at the scale of the Basin is the Tithonian SR (48% of expelled HC) and the Pliensbachian SR (32% of expelled HC, 43% of expelled oil). Callovian SR and Valanginian SR are less significant contributors (respectively 15% and 11% of expelled gas), and contribution of Aptian SR is negligible.
Graphs show that Pliensbachian SR is the only oil prone Source Rock, while Valanginian SR is a clear gas prone Source Rock.

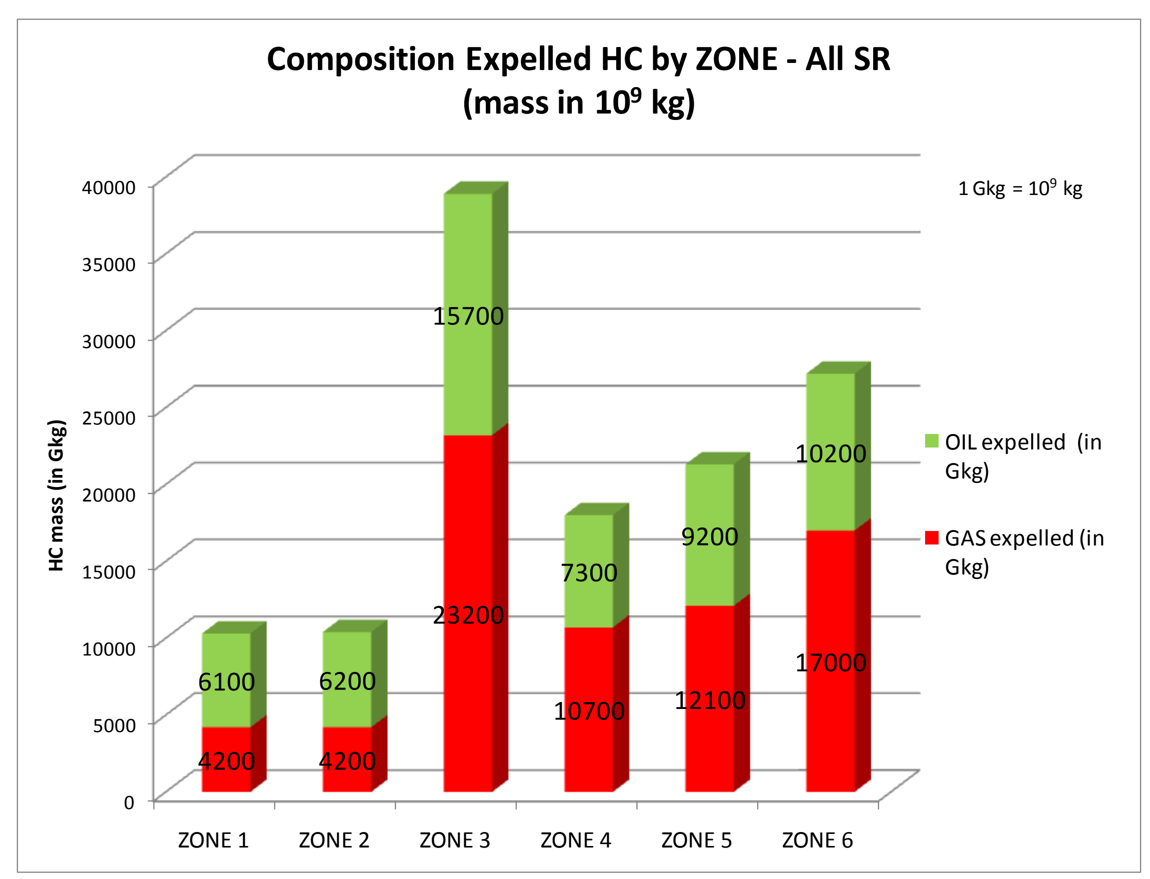
BY ZONE

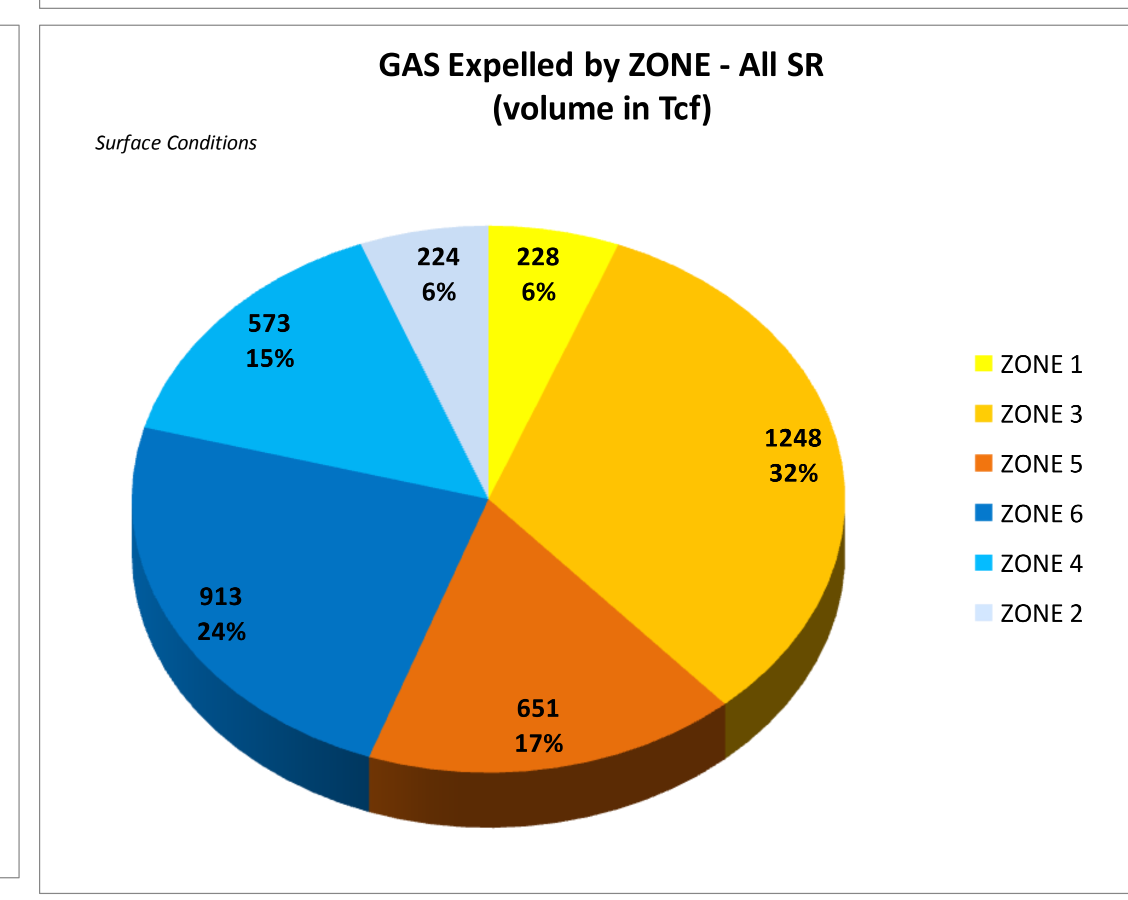
Zones with largest amount of expelled HC are:
→Zone 3 (31%), Zone 6 (22%), Zone 5 (17%), Zone 4 (14%), Zone 2 and Zone 1.
Zone ranking for oil or gas expulsion is the same.

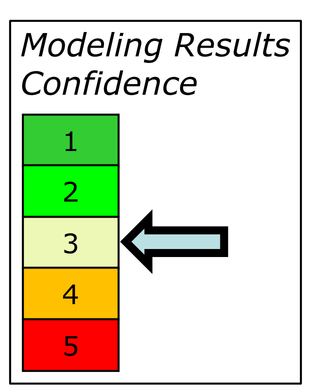
Surface volumes are calculated with d_{oil} = 807 kg/m³ d_{gas} = 0.657 kg/m³.











CHAPTER 7-3

BASIN MODELING – TEMIS 3D

7-3-3

Play System Modeling

Concept of Source Rock Efficiency

"SR efficiencies" used in PetPot correspond to the ratio of hydrocarbons expelled from a given SR reaching a given reservoir through geological times. It is expressed in %. The "SR efficiency" is higher than the "Migration efficiency", usually expressed as:

$$\text{Migration Efficiency} = \frac{\text{HC mass in a trap (present day)}}{\text{HC mass expelled in the corresponding drainage area}}$$

TEMIS 2D® simulations in "full Darcy migration" (Chapter 7-2) give a first estimation of these parameters. In such 2D simulations "Efficiencies" are not input parameters but calculated by the software, taking into account complex migration processes (including the modeling of rocks petrophysical properties, HC geochemical properties, PVT conditions, maturation timings, etc.). Result are averaged and extrapolated in 3D.

The model is also calibrated with field data (known petroleum fields). If calculated HC volumes do not match known HC volumes, Source Rock efficiencies are adjusted.

Geological concepts, knowledge on petroleum system dynamics, and analogs, give precious information too.

In that study case a simplified set of "SR efficiencies" has been approximated by all these means. A lower efficiency is assumed for downward migration. This scheme is conceptual and uncertain but it calibrates known petroleum fields.

The following "SR efficiencies" are defined for each system {SR // Reservoir layers}:

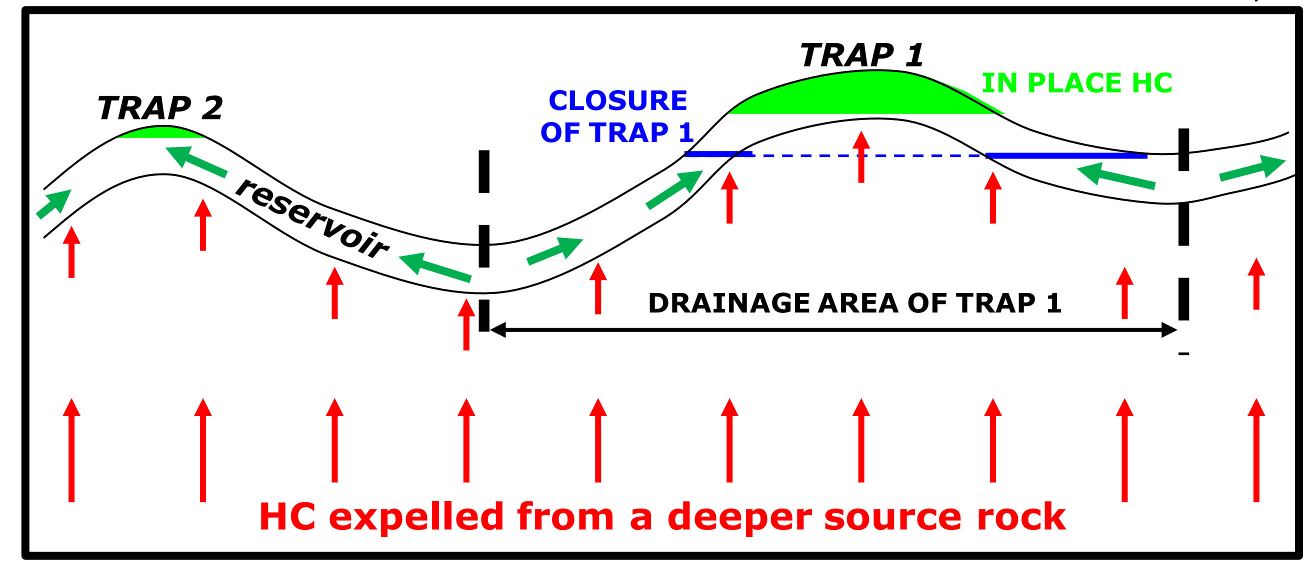
Source Rock Layer / *Reservoir Layer*	APTIAN SR	VALANGINIAN SR	TITHONIAN SR	CALLOVIAN SR	PLIENBACHIAN SR
Aptian-Albian-Cenomanian (K112-K94)	**5%**	3%	3%	1%	1%
Hauterivian-Barremian (K130-K123)	3%	**5%**	5%	3%	1%
Berriasian-Valanginian-Hauterivian (J150-K130)	0%	3%	**5%**	3%	3%
Oxfordian-Tithonian (J63-J150)	0%	0%	3%	**5%**	3%
Early-Middle-Jurassic (J200-J163)	0%	0%	0%	3%	**5%**

Downward migration

The 2nd **modeling stage** consists in determining main reservoir characteristics and charge for each **play system**, at the scale of each subzone:

- Temperature / pressure / secondary cracking and biodegradation risk
- **Drainage area maps** and main **closure maps** → ***"Drains" Module***
- **Trapped HC volumes** (in place) and HC characteristics → ***"PetPot" Module***
- SRs contribution

DRAIN and PETPOT Concept



"**Drain**" and "**Petpot**" modules of Temis 3D® take into account:

- HC volumes expelled by each SR through geological time
- Porous volume change through geological time (compaction)
- Structural and drainage changes through geological time
- Structural and closure changes through geological time
- Pressure and temperature changes through geological time (PVT)

Migration and Accumulation Modeling (Play System Modeling) directly uses results of the Temperature / Pressure / Maturity / Expulsion Modeling, and is constrained by reservoir layers definition in the 3D block (structural maps, thickness maps, facies maps).

NOTE: Results are calibrated with field data (mainly in the Subzone 3).

HYPOTHESIS for the DRAINAGE ANALYSIS (Drain Module)

→ "Drain" and "Petpot" use a simplified version of the TEMIS 3D block. Only SR and Reservoir layers are considered for drain and migration modeling. Structural maps have the highest available resolution.

→ Only 4 way traps with a closure surface bigger than 2 km² are considered. Most of fields in the Sable Sub Basin are associated to rollover with a spill point against "relatively" permeable faults. This assumption is not restrictive at the scale of the basin, given the lateral resolution of structural data (1 km). Closed areas, closure heights, and closed volumes, are computed.

→ To each trap corresponds a drainage area. A leakage network exists between traps.

→ Inside reservoir layers, HCs migrate laterally up to a trap or a permeable fault. Migration pathways are defined by slope lines. Combinations of migration pathways define drainage areas.

→ Salt bodies are impermeable and are excluded from drainage areas.

→ Most of salt bodies are bordered by "relatively" permeable faults. Closure against diapirs are unlikely (assumption based on observations, such as "seeps" in the salt basin, or absence of such traps in the Sable Sub Basin).

→ HCs that reach a permeable faults or the model border are lost.

→ The migration in each reservoir layer is computed independently.

NOTE: *New drainage areas are computed for each time step.*

HYPOTHESIS for the MIGRATION / ACCUMULATION ANALYSIS (PetPot Module)

→ Between source rocks and reservoir layers, upward and downward migration is assumed vertical and instantaneous (at each time step). At the scale of the basin this assumption is correct and consistent.

→ A "SR efficiency" is defined for each couple {SR // Reservoir layers}, see verso..

→ In each trap the PetPot module defines:
- The volume of different **phases** (liquid, vapor, critical fluid)
- The composition of different phases (**"oil" fractions** C6+, **"gas" fraction** C1-C5).
- Various petroleum parameters such as the CGR, the GOR, the API.

→ It is possible to identify relative SR contribution.

→ Leakage through spill points depends on **PVT conditions** (volume in bottom conditions for different phases, water/oil contact and gas/oil contact), and on the **porous volume** at each time step.

→ Volumes in surface condition are computed with:
- API gravities for the Oil,
- V=nRT/P for the gas (with P=0.1MPa, T=20°C, n=16 if methane is dominant).

NOTE: *New volumes and phases are computed for each time step.*

NOTE: *"PHASES" and "FRACTIONS" are different concepts.*

→ **5 PLAY SYSTEMS** are studied (see PL. 7-3-1-5)

→ All volumes and masses calculated by PetPot are **IN PLACE**. The software considers only HC trapped in structures (of any size).

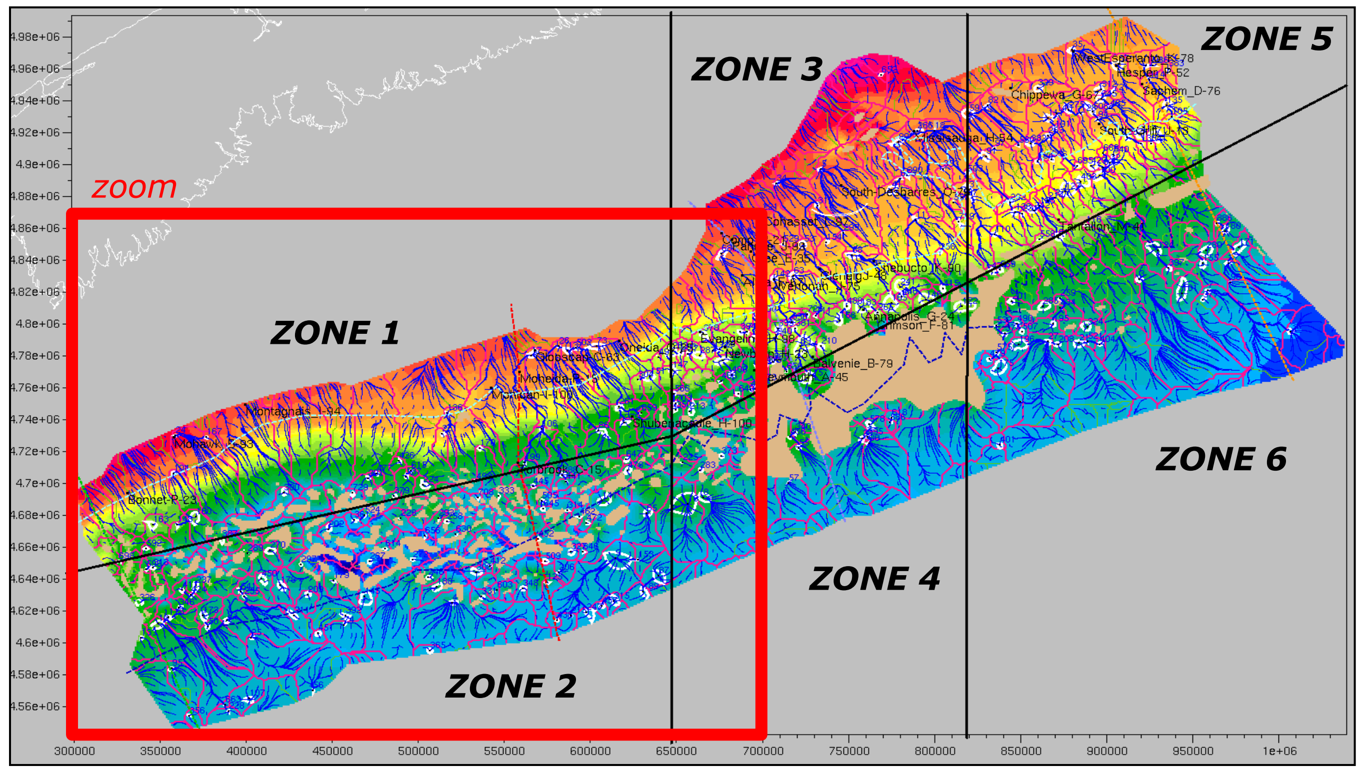
→ Volumes and masses are **UNRISKED**.

→ Volumes calculated by Temis® are **equivalent to P10 VOLUMES** (optimistic scenario): 5 potential Source Rocks and 5 plays are considered.

→ Masses and volumes are computed in International Units and converted in Imperial Units.

→ It is better to manage masses rather than volumes in intermediary results (comparing easily amounts of oil and gas, avoiding uncertainties on conversions in surface condition).

→ There is no indication on the distribution of HCs within each subzone. This distribution may be heterogeneous, particularly in Zone 1.



Due to the complex shape of drainage areas in Zone 2 (salt mini-basins), long-distance lateral migration is unlikely in that part of the basin. Moreover the existence of relatively permeable faults along active salt bodies would increase the vertical migration, and so the hydrocarbon "leakage" out of this play (presence of seeps in this area). As a consequence potential mature SR in Zone 2 can hardly feed reservoirs in Zone 1. Potential migration pathways are longer in the upper slope and on the platform (Zone 1).

Albian-Cenomanian – SW

PLAY SYSTEMS
Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J163-J150)
Early-Middle-Jurassic (J200-J163)

Zone	Zone Total Surface (km^2)	Number of Traps (trap surface > 2 km^2)	Number of Traps per 1000 km^2	Total Closed Areas **in km^2** (sum of traps surface if surface > 2 km^2)	% Closed Areas (/ zone total surface)	Average Drainage Area Surface **in km^2**	Total Closed Porous Volume **in Mm^3** (sum of traps volume)	Total Closed Porous Volume **in Billion bbl** (sum of traps volume)
Whole Basin	**141963**	**299**	**2.1**	**3280**	**2%**	**260**	**12400**	**78**
ZONE 1	26806	34	1.3	300	1%	300	500	3
ZONE 2	33263	87	2.6	820	2%	200	700	4
ZONE 3	24769	67	2.7	710	3%	240	4500	28
ZONE 4	18250	20	1.1	330	2%	360	1000	6
ZONE 5	14694	53	3.6	600	4%	240	4200	26
ZONE 6	24181	40	1.7	520	2%	360	1500	9

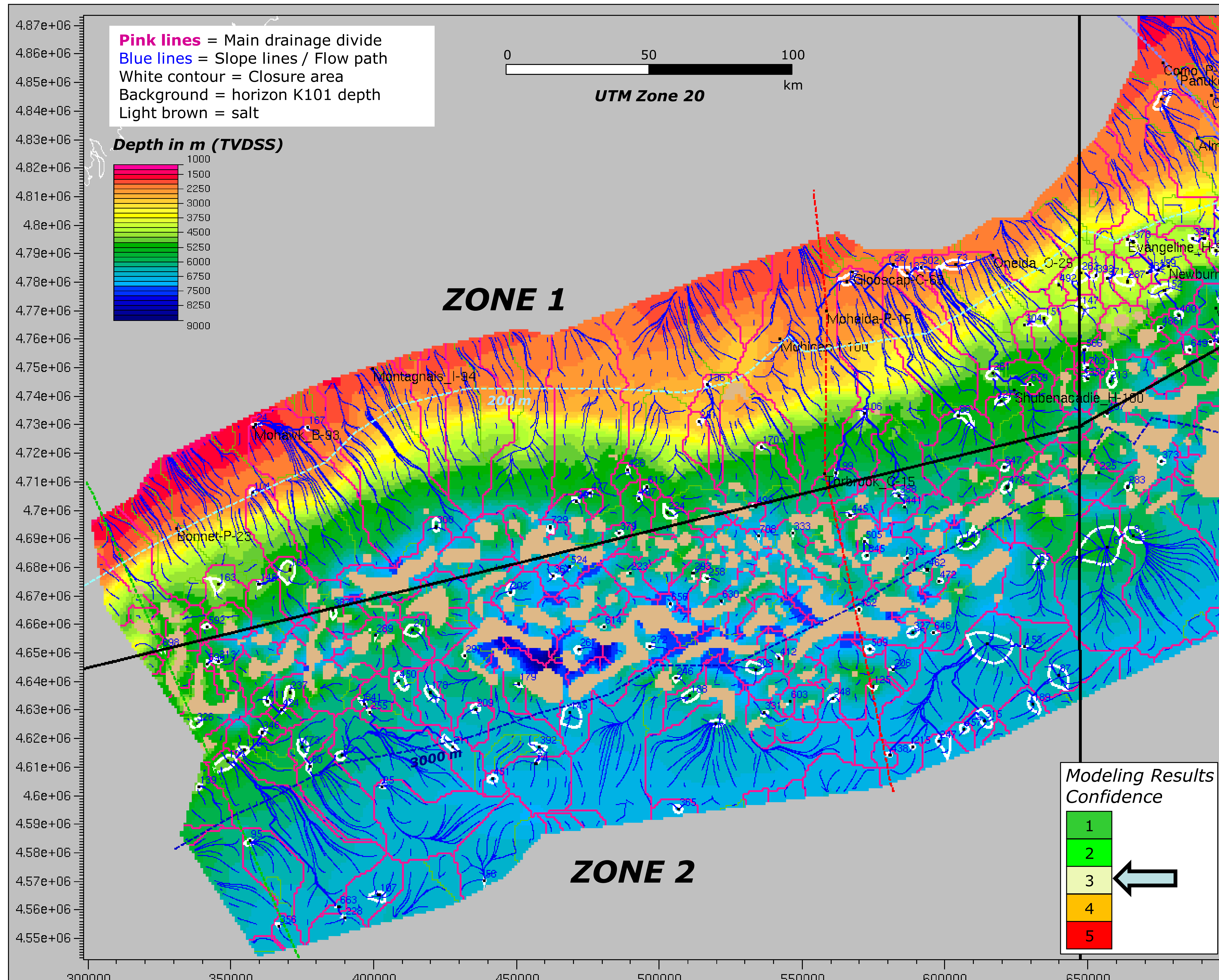
CLOSED AREAS / CLOSED POROUS VOLUMES / DRAINAGE AREAS

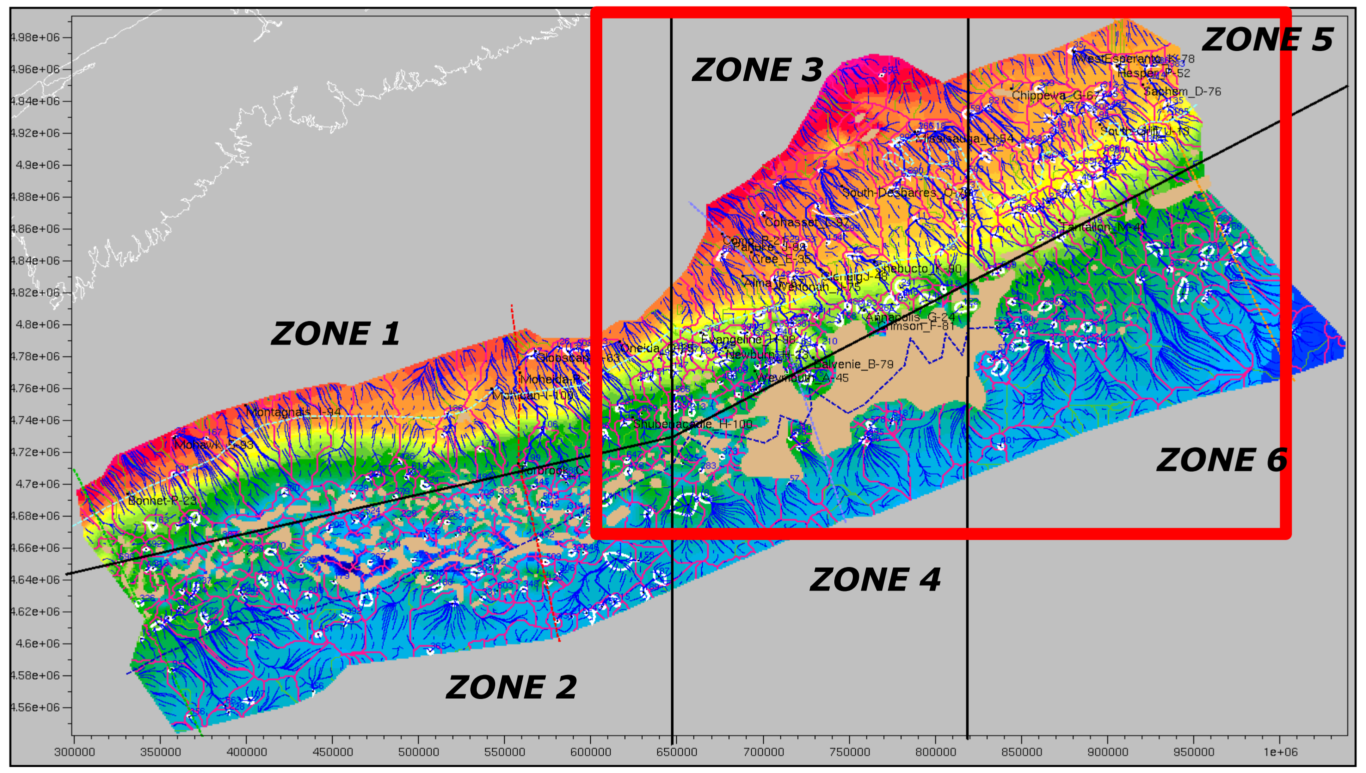
The **closed area** (or closure area) is defined by structural maps. It corresponds to the extend of a structural trap (4 way closure). About 2% of the study area is a closed area. Closed areas evolve during the geological history due to structural evolutions.

The **closed porous volume** is the volume of voids in a structural trap. This volume can be filled with water or hydrocarbons. It usually decreases during the geological history due to the compaction. Porosity modeling is done by Temis®.

Each trap is associated to a **drainage area** defined by slope lines, impermeable lithologies, permeable faults. The size of the drainage area may impact the charge of the trap.

The **Albian-Cenomanian play system** includes: the Cree Formation Play, the Logan Canyon Play, the Albian Low-Stand Sandstone Play, etc.





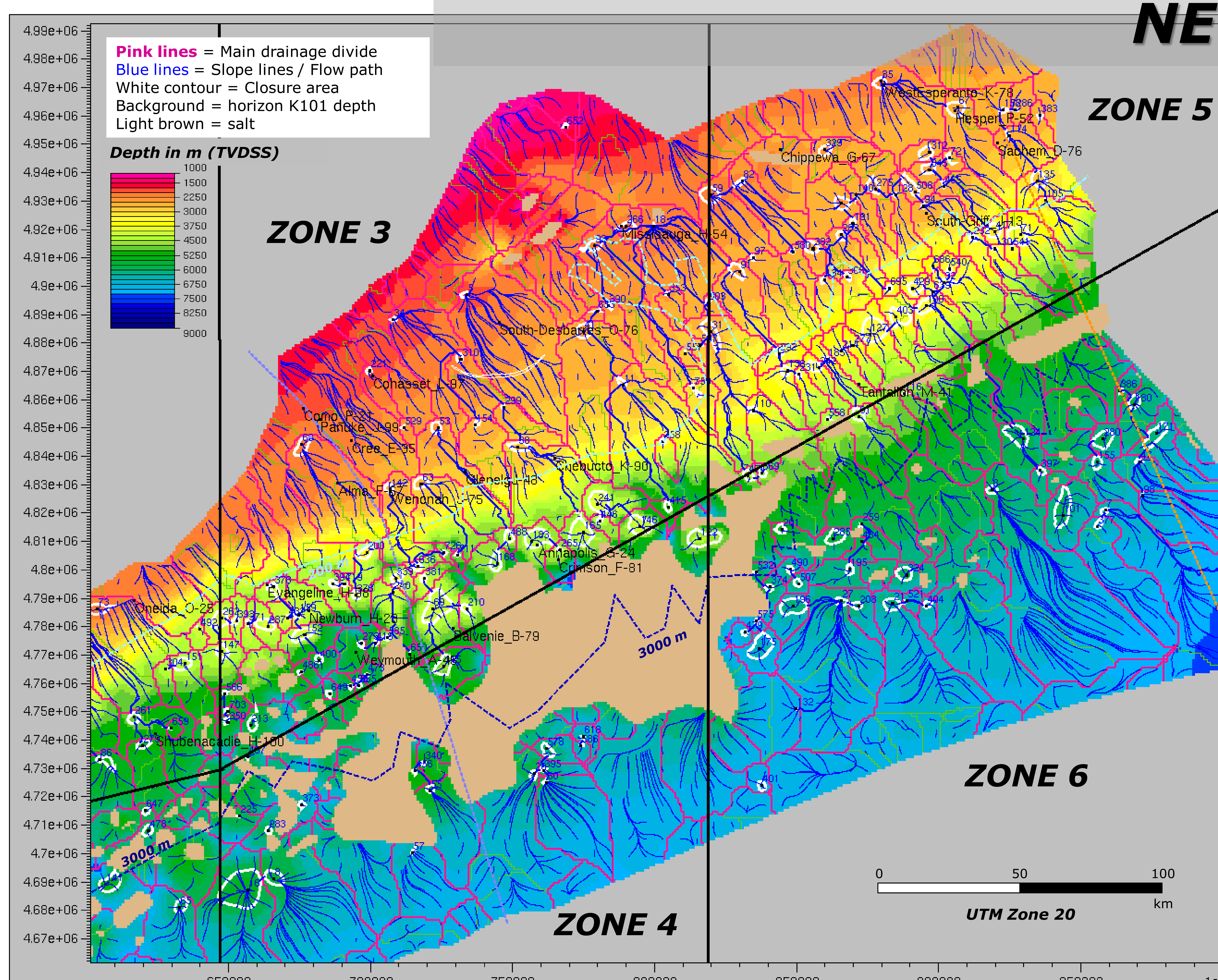
PLAY SYSTEMS
Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J163-J150)
Early-Middle-Jurassic (J200-J163)

Due to the complex shape of drainage areas in salt mini-basins (southern Zone 3, Zone 4), long-distance lateral migration is unlikely south of a line Evangeline-Annapolis.

However , relatively long distance lateral migration appears possible in the Sable Sub Basin (Zone 3) , the play being sourced from mature SR located in the deep depression between Evangeline, Annapolis, and Glenelg (North of the line Evangeline-Annapolis).

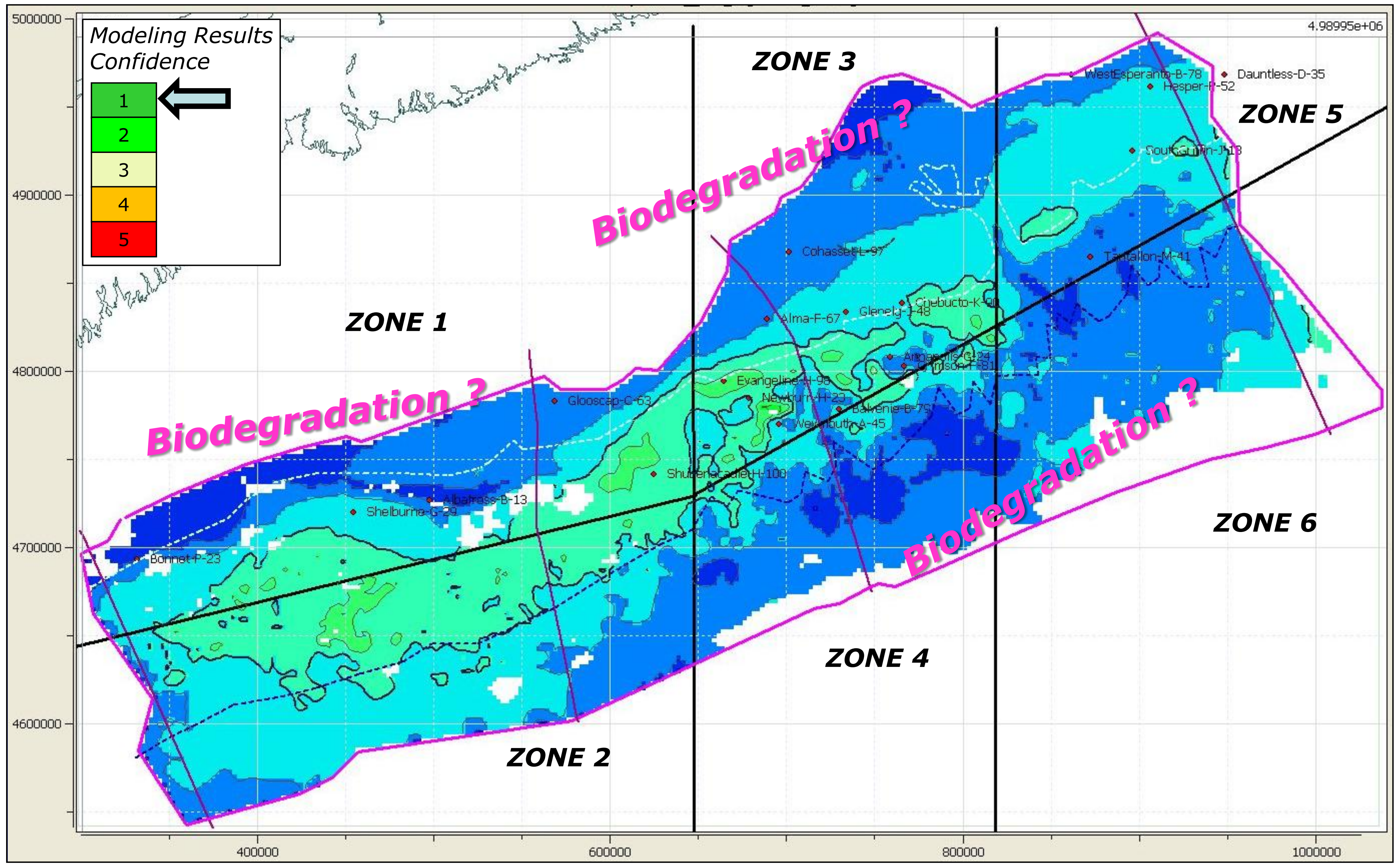
Potential migration pathways are longer in the upper slope and on the platform (zones 3 and 5). Very long horizontal migration pathways are also possible in the deep basin (southern zones 4 and 6)

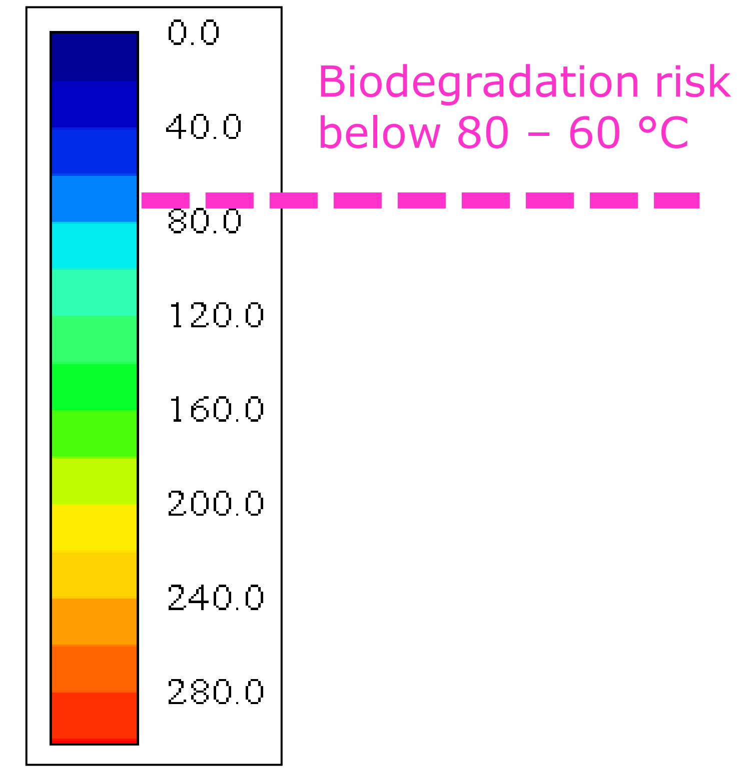
Albian-Cenomanian – NE



Modeling Results Confidence

1	
2	
3	⇦
4	
5	





°C

Temperature at K101

TEMPERATURE / BIODEGRADATION / SECONDARY CRACKING

Temperature reaches a maximum of 130°C in the slope along the shelf break, particularly in zones 1, 2, and 3.

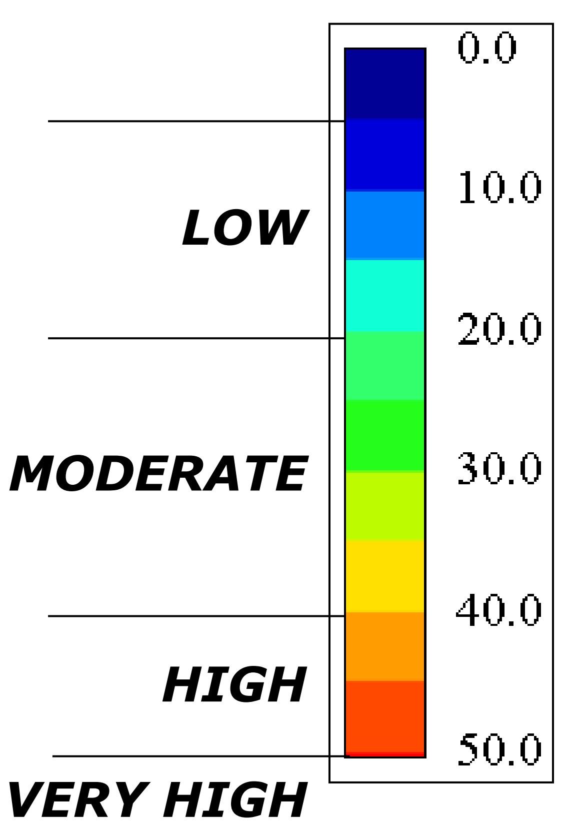
Risk of biodegradation exists on the platform, particularly in zones 1 and 3 (minimum temperature around 50°C), and in the deep basin, particularly in zones 4 and 6.

The possibility of secondary cracking is very limited in the deepest part of the basin, and only concerns the heaviest hydrocarbon fraction.

Albian-Cenomanian Play System

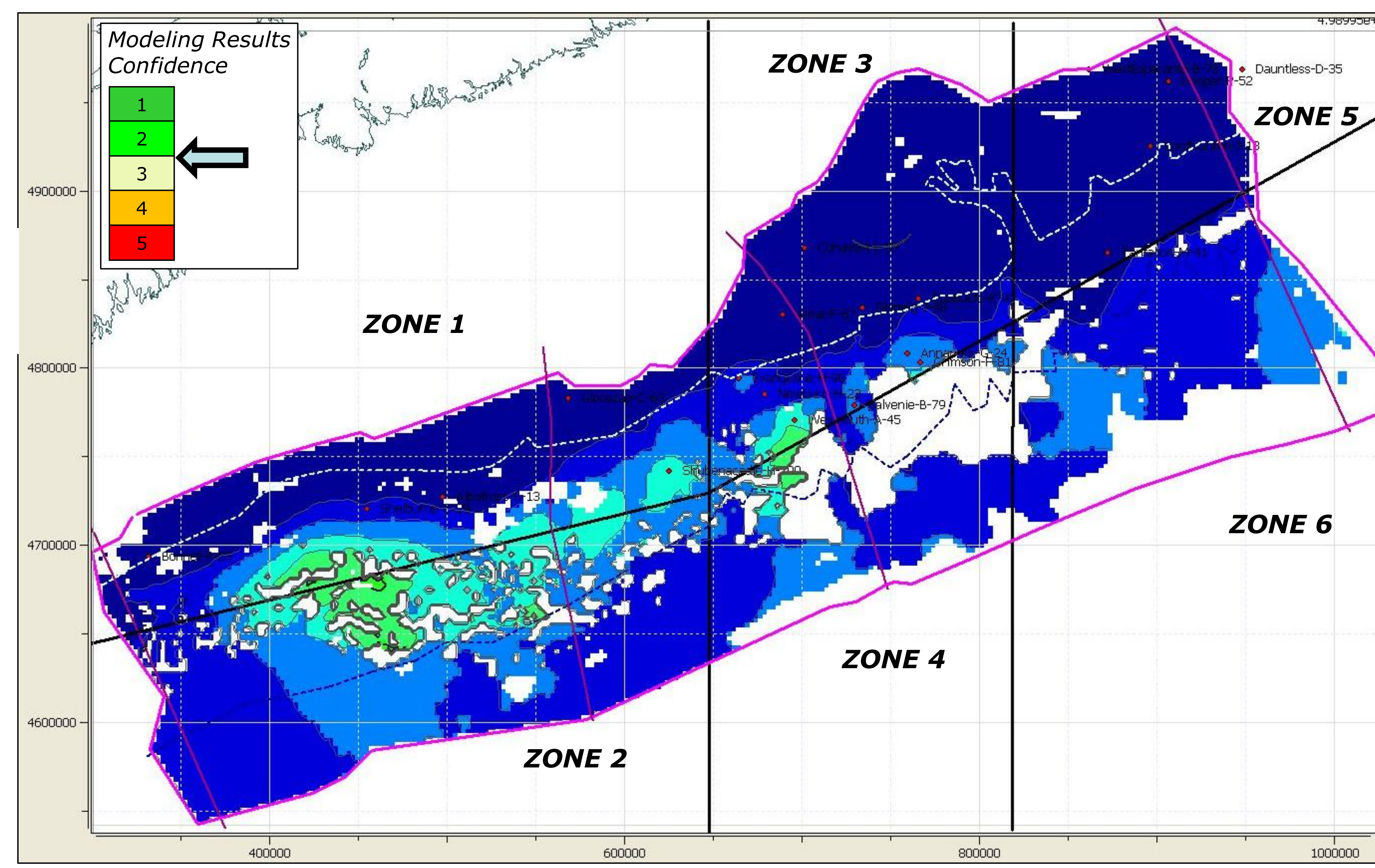
MPa

Overpressure at K101



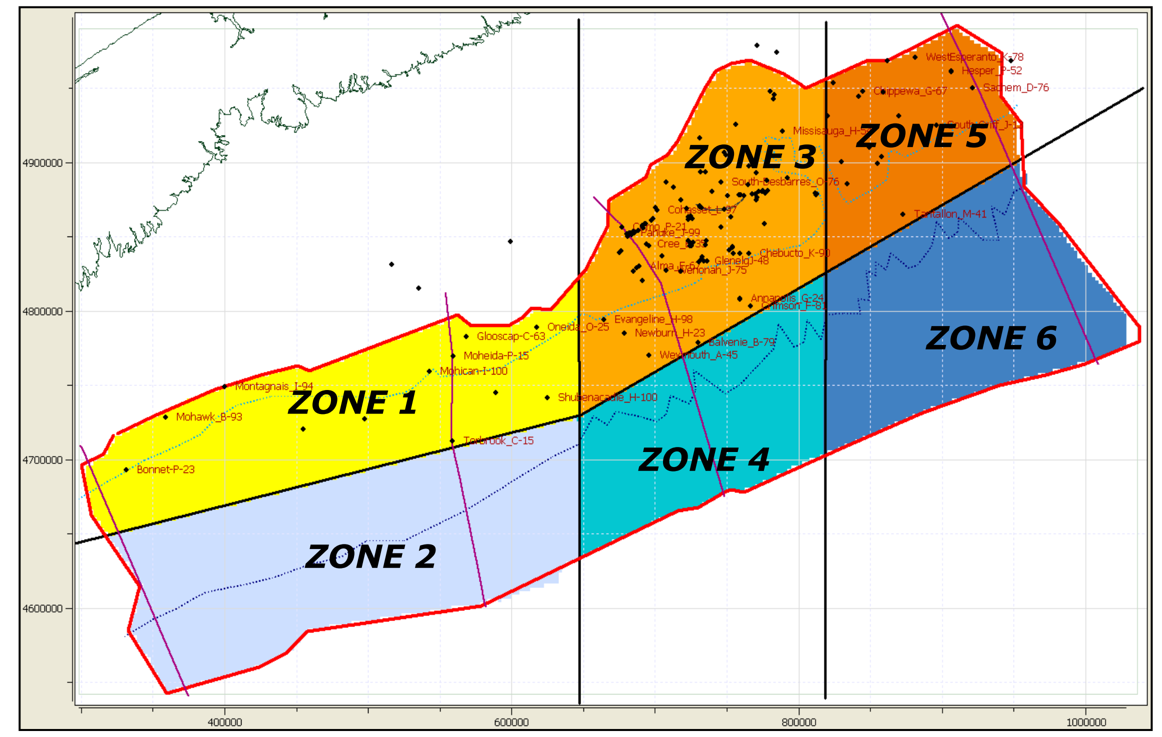
PRESSURE / OVERPRESSURE

Overpressure is low to moderate in the slope along the shelf break, with highest values between zones 1 and 2, and locally between zones 3 and 4, around salt diapirs.
There is no overpressure on the platform, and very low overpressure in the deep basin.
Average value for the whole study area is around 5MPa.

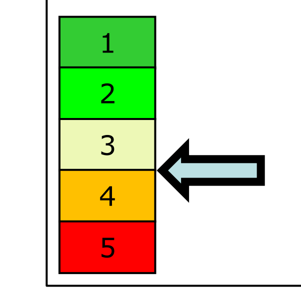


 Play System Modeling – Albian-Cenomanian Sequence (K112-K94) – Temperature and Overpressure

Albian-Cenomanian Play System

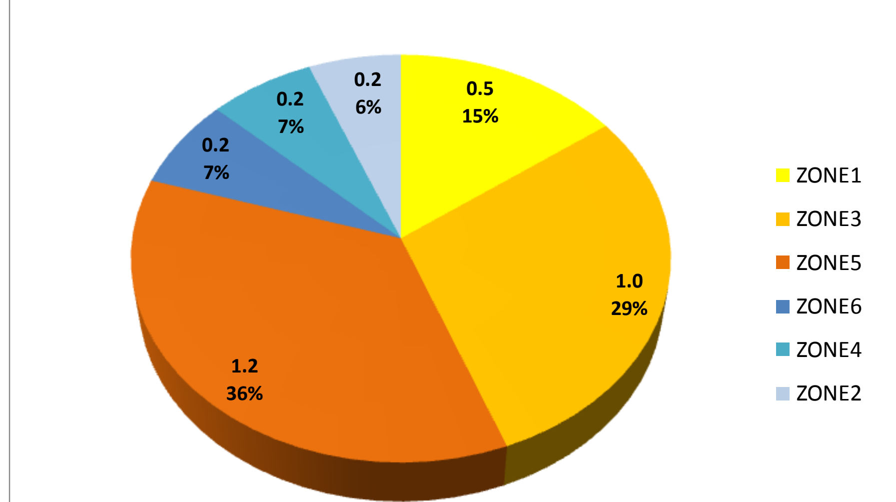


Modeling Results Confidence*



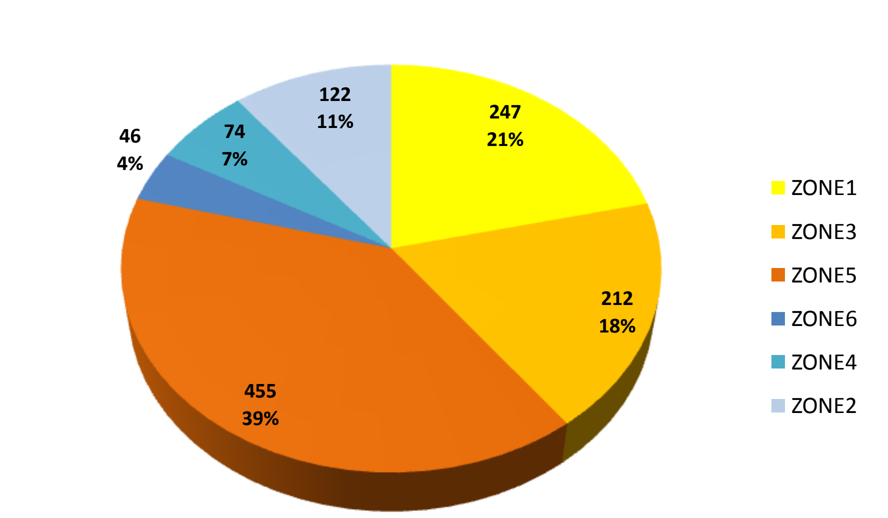
*Except for following results which are only qualitative (4-5): API gravity and HC phase behavior. HC masses are better constrained than HC volumes.

Volume of OIL EQUIVALENT in Place - by Zone
Alb-Ceno. - Surface Conditions (in Billion bble)



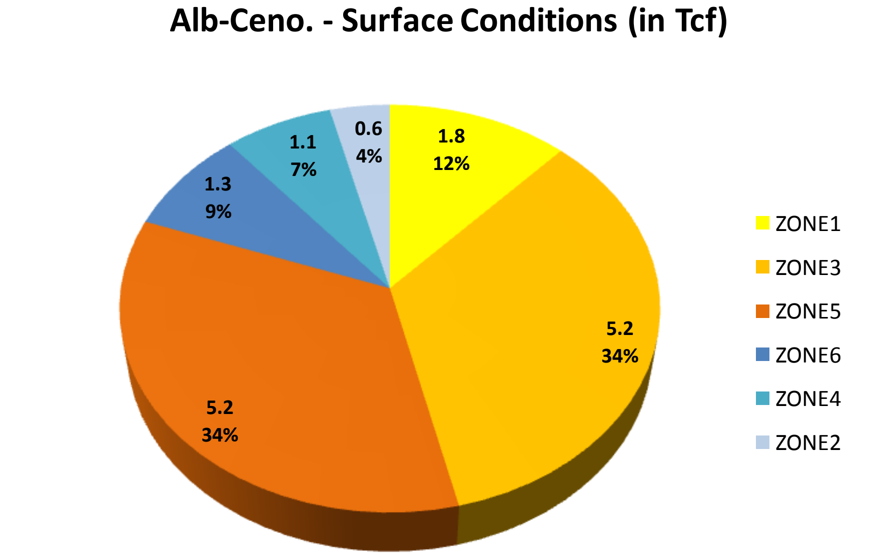
OIL EQUIVALENT In Place = 3.3 Billion bble

Volume of OIL in Place - by Zone
Alb-Ceno. - Surface Conditions (in Mbbl)



OIL In Place = 1.2 Billion bbl

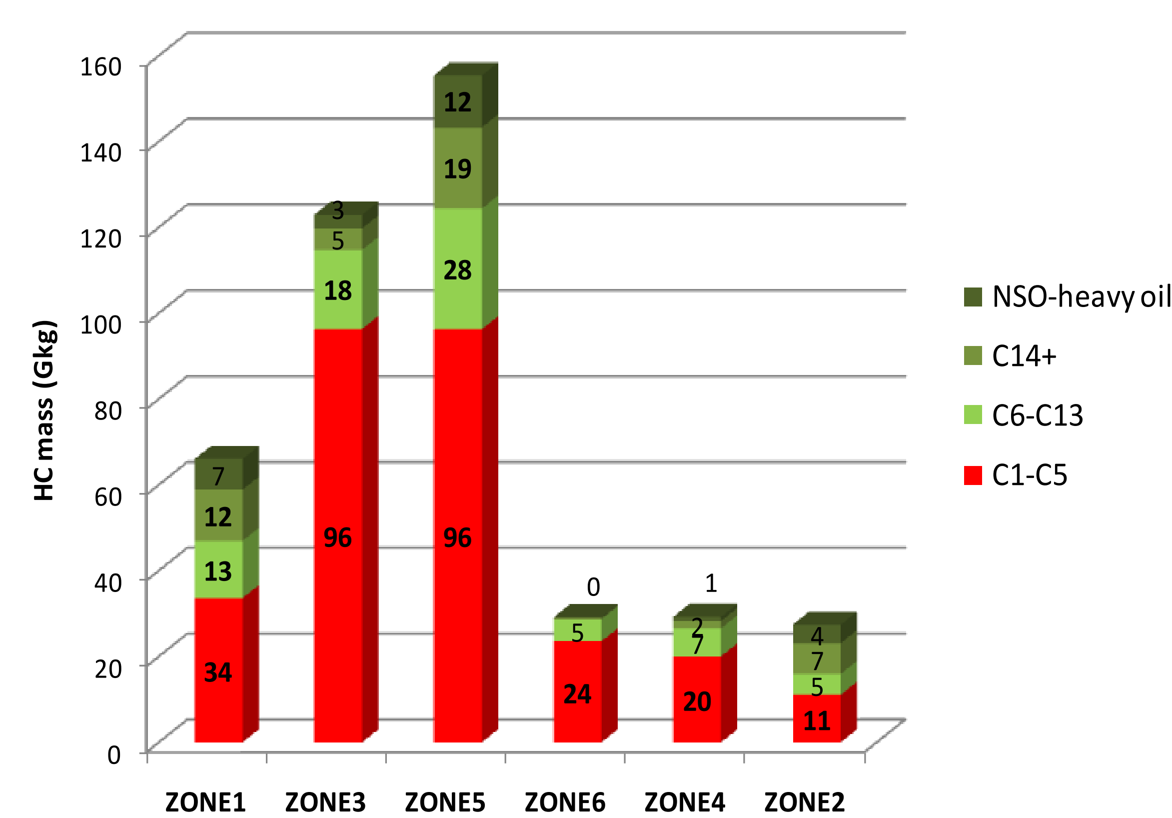
Volume of GAS in Place - by Zone
Alb-Ceno. - Surface Conditions (in Tcf)



GAS In Place = 15 Tcf

HC Repartition
(masses and volumes – by Zone)

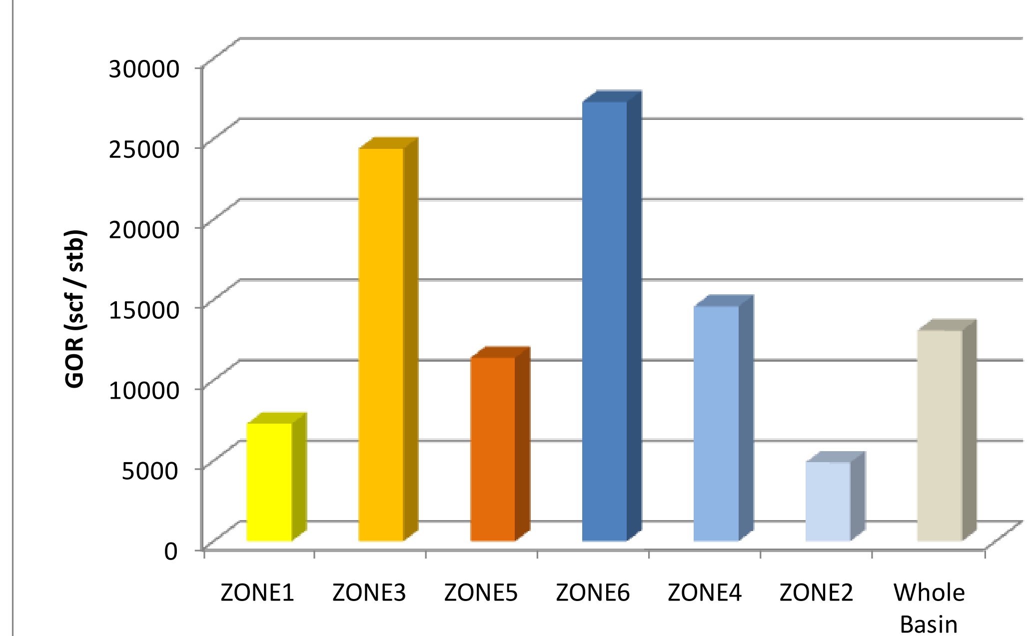
HC type by zones (in Gkg) - Apt-Ceno.



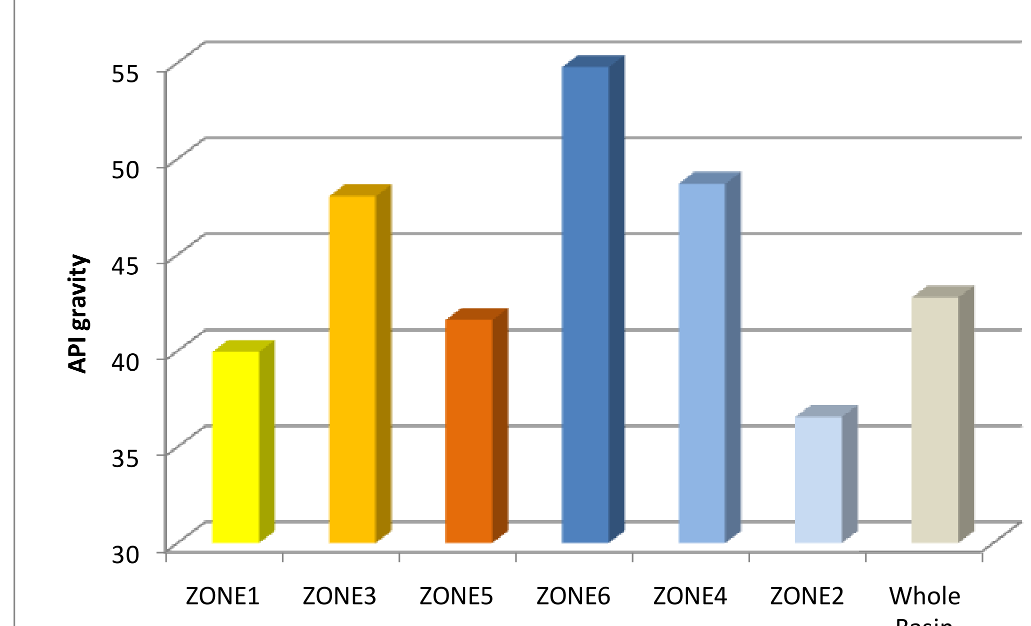
By ZONE Alb-Ceno.	TOTAL GAS Mass (Gkg) In Place - Unrisked	TOTAL OIL mass (Gkg) In Place - Unrisked	TOTAL HC mass (Gkg) In Place - Unrisked	TOTAL GAS volume in surface (Tcf) In Place - Unrisked	TOTAL OIL volume in surface (Mbbl) In Place - Unrisked	TOTAL OIL EQUIVALENT volume in surface (Million bble) In Place - Unrisked
ZONE1	34	32	66	1.8	250	500
ZONE3	96	27	123	5.2	210	1000
ZONE5	96	59	155	5.2	460	1200
ZONE6	24	6	29	1.3	50	200
ZONE4	20	9	29	1.1	70	200
ZONE2	11	16	27	0.6	120	200
Whole Basin	281	149	430	15	1160	3300

HC Characteristics
(Composition / Phase / Origin)

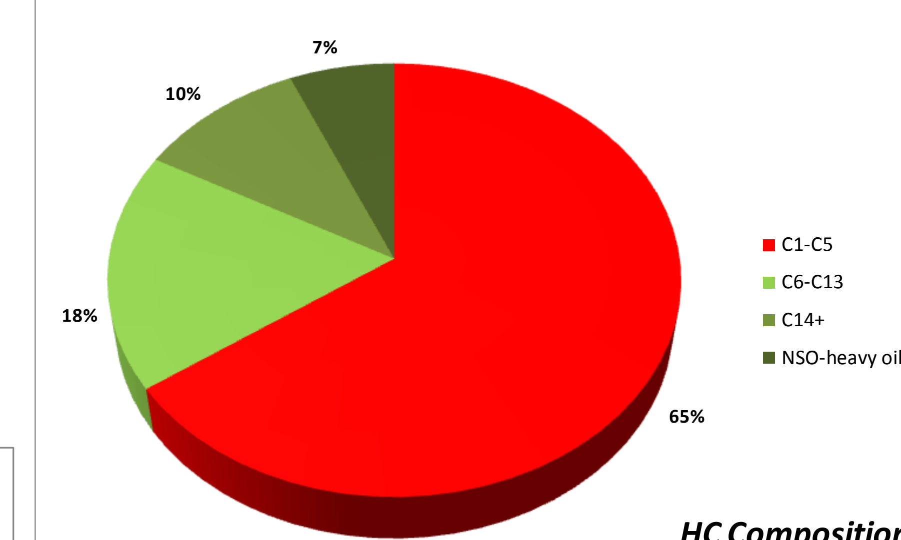
GOR by Zones (scf /stb) - Apt-Ceno.



API Gravity by Zones - Alb-Ceno.

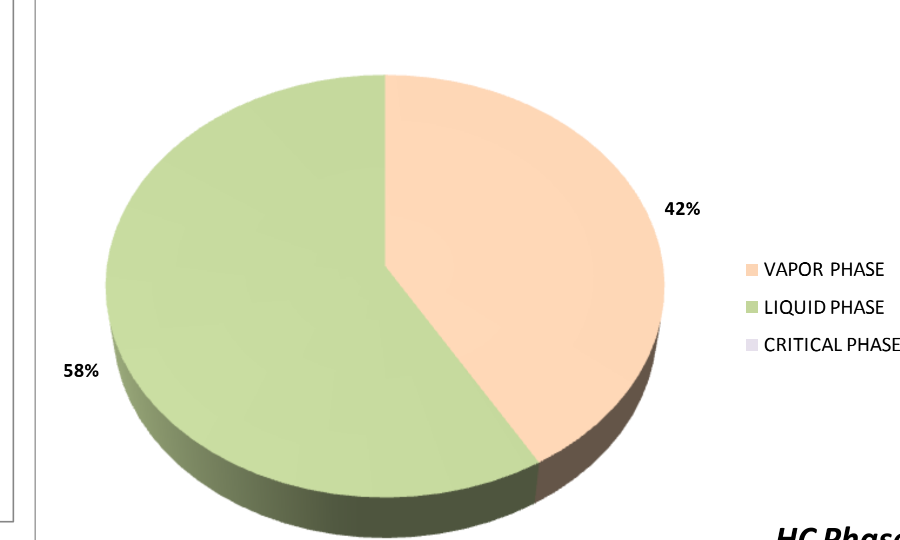


Whole Basin - Alb-Ceno. (% mass)



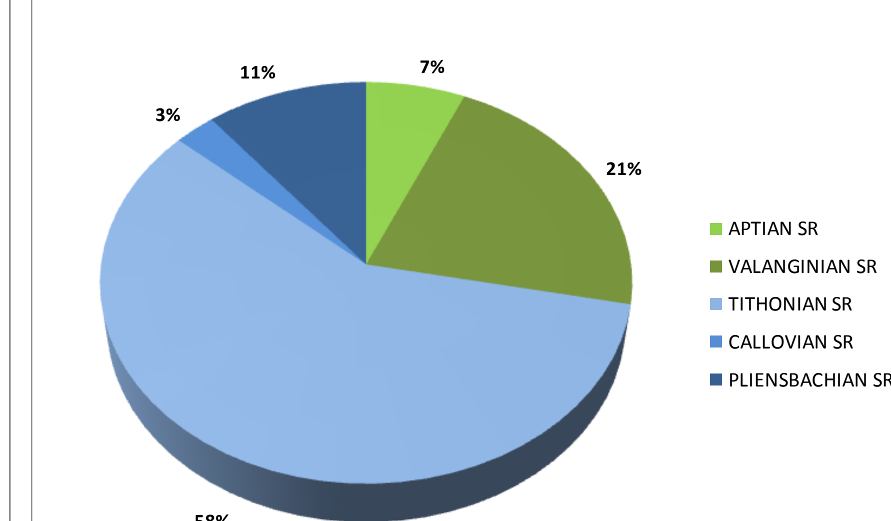
HC Composition
Chemical Fractions

Whole Basin - Alb-Ceno. (% mass)

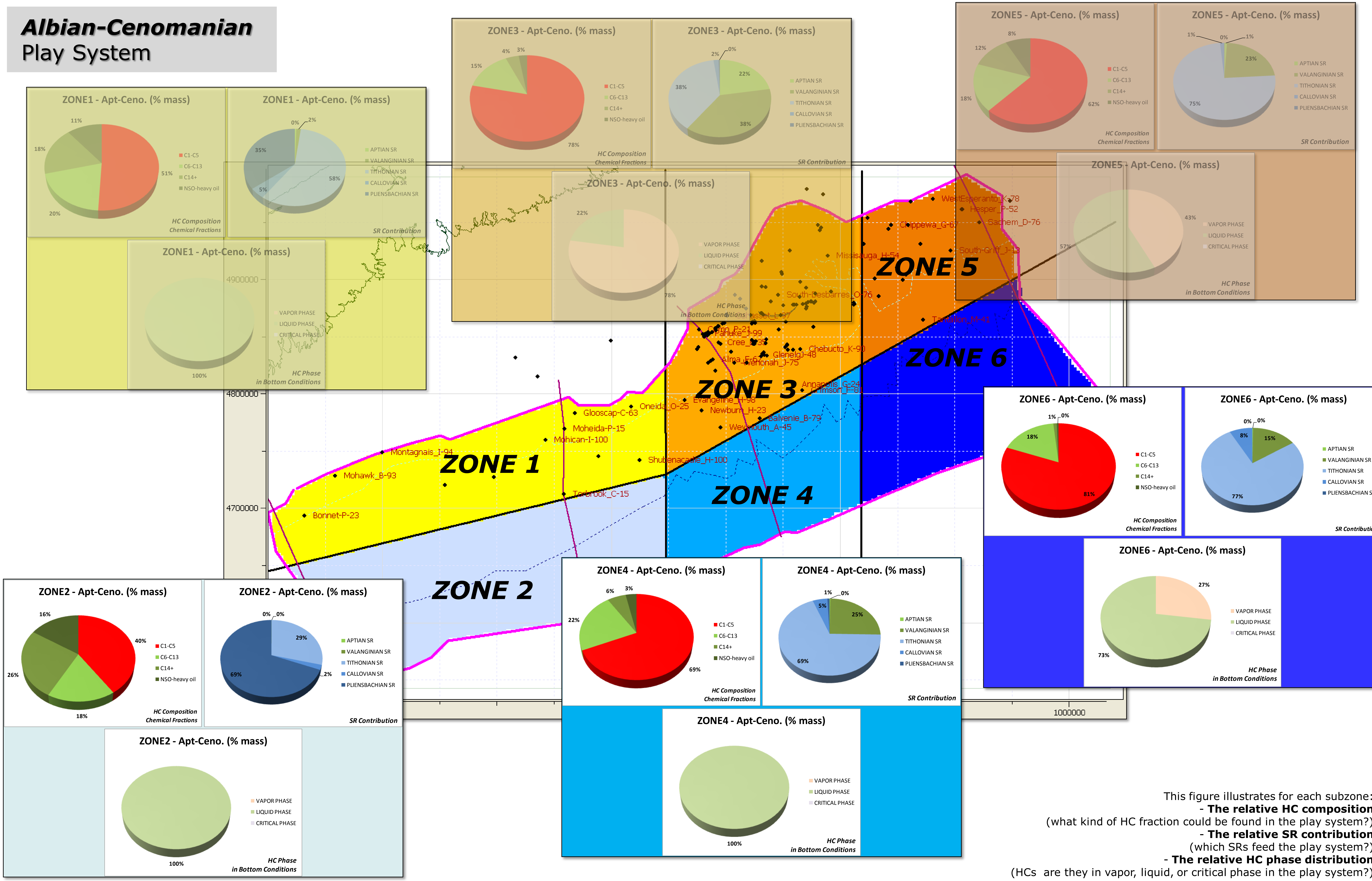


HC Phase
in Bottom Conditions

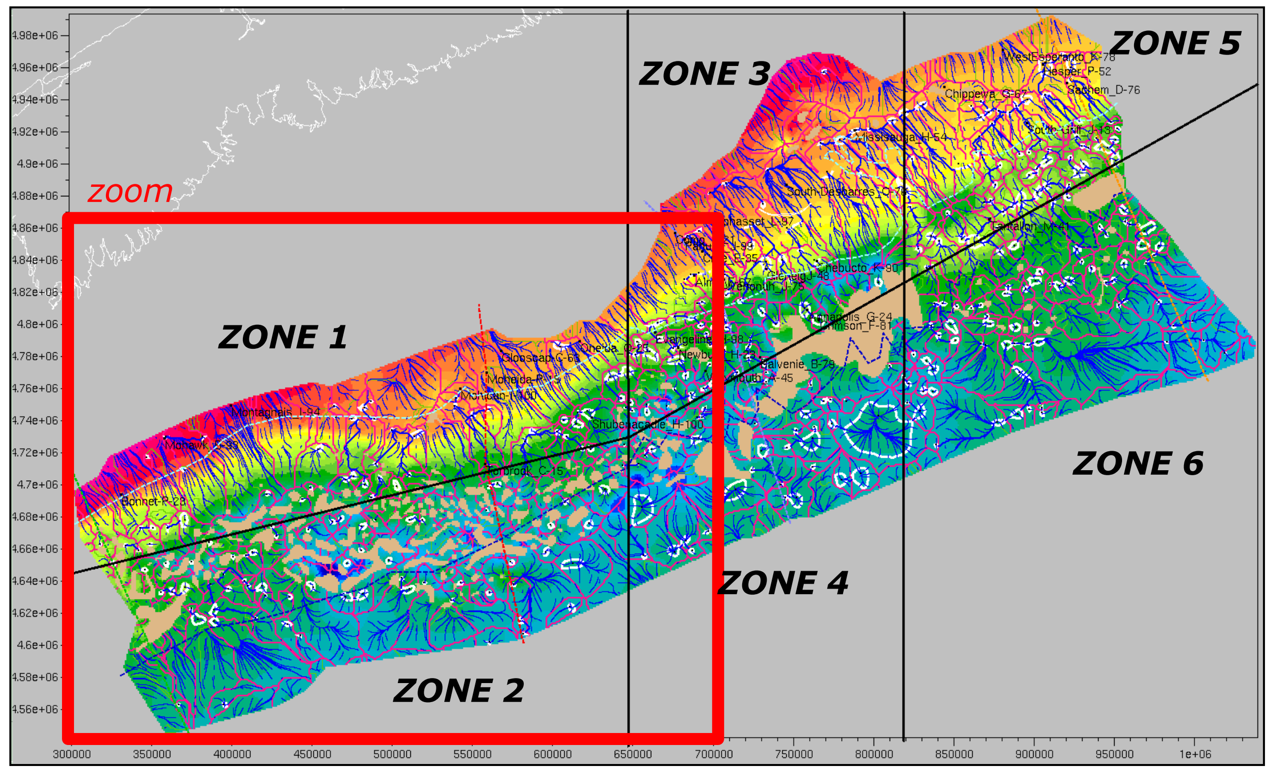
Whole Basin - Alb-Ceno. (% mass)



SR Contribution



This figure illustrates for each subzone:
- **The relative HC composition**
(what kind of HC fraction could be found in the play system?)
- **The relative SR contribution**
(which SRs feed the play system?)
- **The relative HC phase distribution**
(HCs are they in vapor, liquid, or critical phase in the play system?)



PLAY SYSTEMS
Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J163-J150)
Early-Middle-Jurassic (J200-J163)

Zone	Zone Total Surface (km^2)	Number of Traps (trap surface > 2 km^2)	Number of Traps per 1000 km^2	Total Closed Areas in km^2 (sum of traps surface if surface > 2 km^2)	% Closed Areas (/ zone total surface)	Average Drainage Area Surface in km^2	Total Closed Porous Volume in Mm^3 (sum of traps volume)	Total Closed Porous Volume in Billion bbl (sum of traps volume)
Whole Basin	**141963**	**367**	**2.6**	**4900**	**3%**	**230**	**21500**	**135**
ZONE 1	26806	52	1.9	390	1%	220	500	3
ZONE 2	33263	69	2.1	600	2%	210	600	4
ZONE 3	24769	68	2.7	620	3%	230	2800	18
ZONE 4	18250	43	2.4	1820	10%	240	13300	84
ZONE 5	14694	61	4.2	630	4%	180	2500	16
ZONE 6	24181	74	3.1	840	3%	270	1900	12

CLOSED AREAS / CLOSED POROUS VOLUMES / DRAINAGE AREAS

The **closed area** (or closure area) is defined by structural maps. It corresponds to the extend of a structural trap (4 way closure). About 2% of the study area is a closed area. Closed areas evolves during the geological history due to structural evolutions.

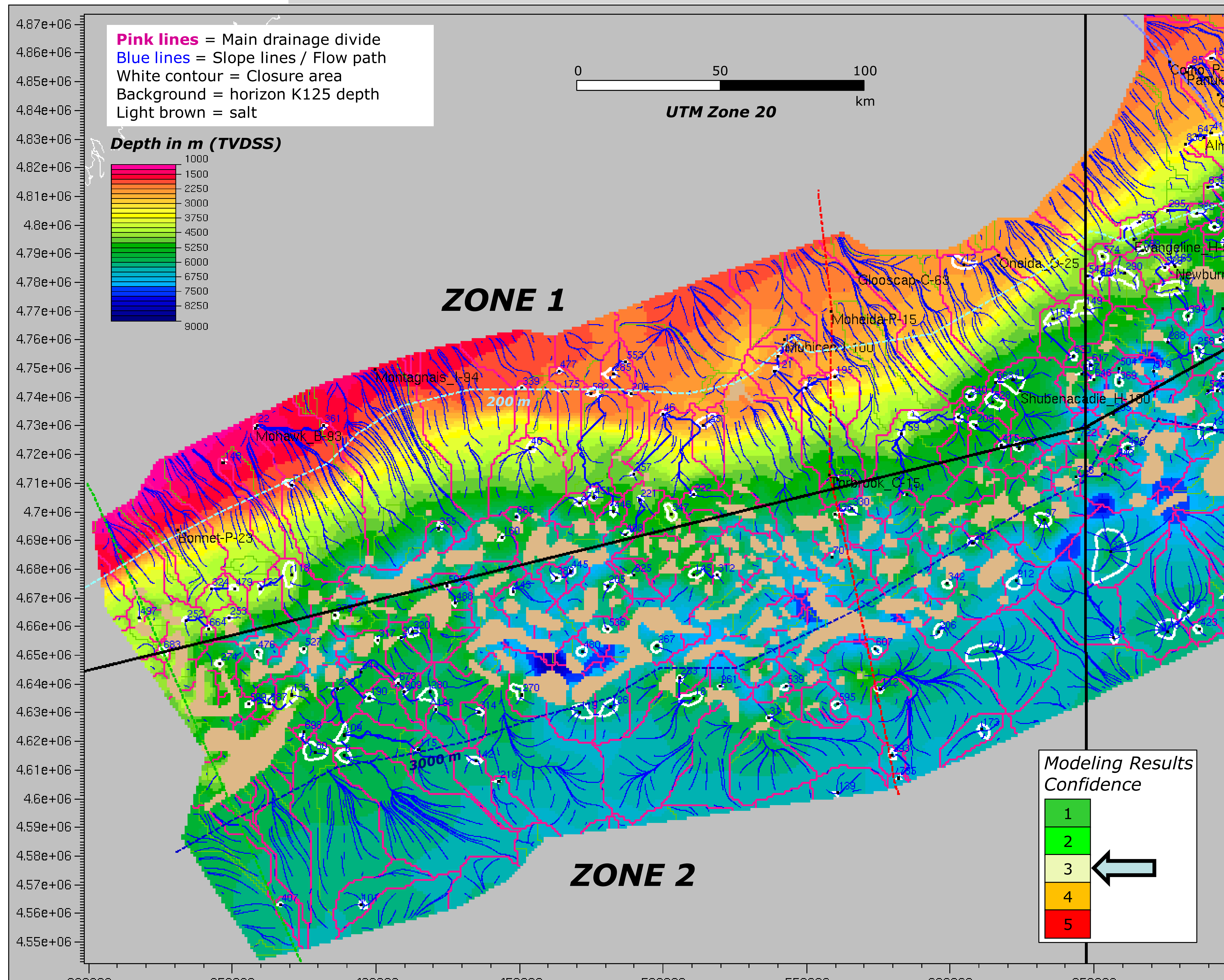
The **closed porous volume** is the volume of voids in a structural trap. This volume can be filled with water or hydrocarbons. It usually decreases during the geological history due to the compaction. Porosity modeling is done by Temis®.

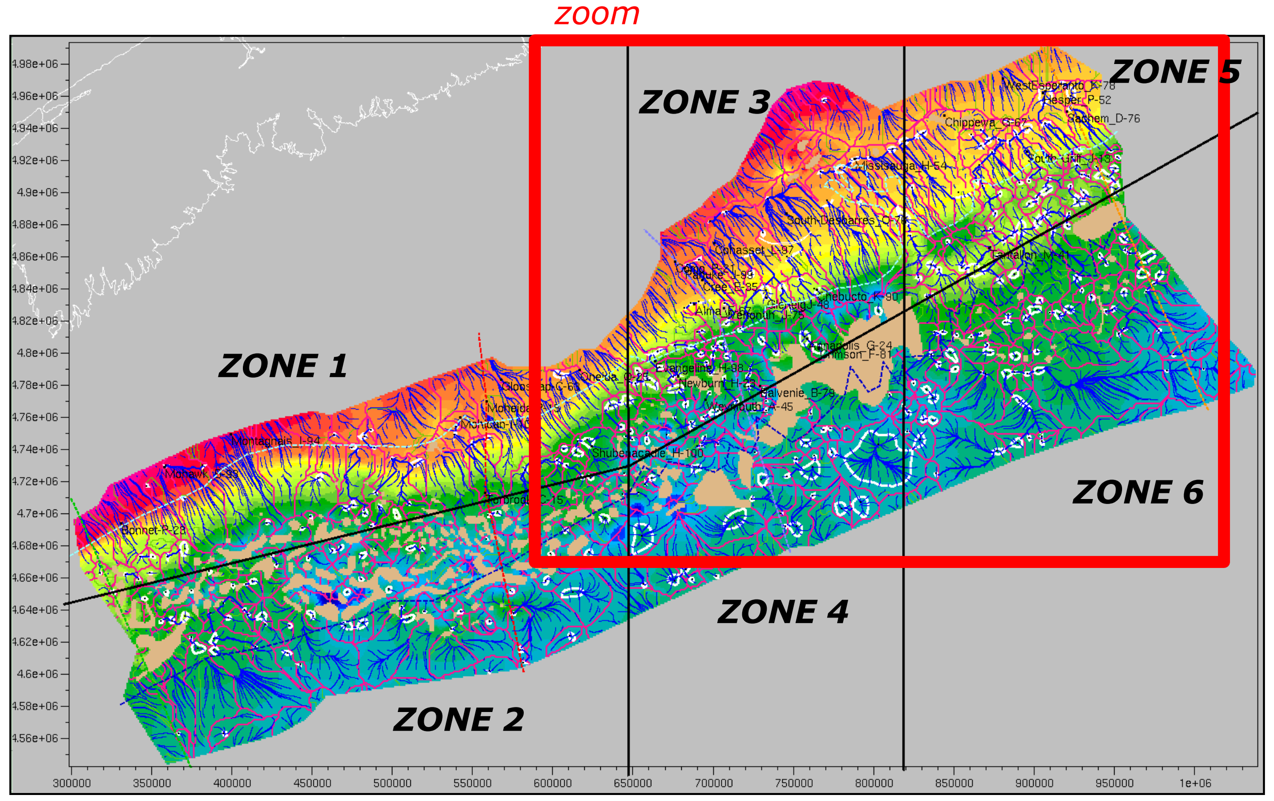
Each trap is associated to a **drainage area** defined by slope lines, impermeable lithologies, permeable faults. The size of the drainage area may impact the charge of the trap.

The **Hauterivian-Barremian play system** mainly includes the Upper Mississauga Formation Play.

Due to the complex shape of drainage areas in Zone 2 (salt mini-basins), long-distance lateral migration is unlikely in that part of the basin. Moreover the existence of relatively permeable faults along active salt bodies would increase the vertical migration, and so the hydrocarbon "leakage" out of this play (presence of seeps in this area). As a consequence potential mature SR in Zone 2 can hardly feed reservoirs in Zone 1. Potential migration pathways are longer in the upper slope and on the platform (Zone 1).

Hauterivian-Barremian – SW





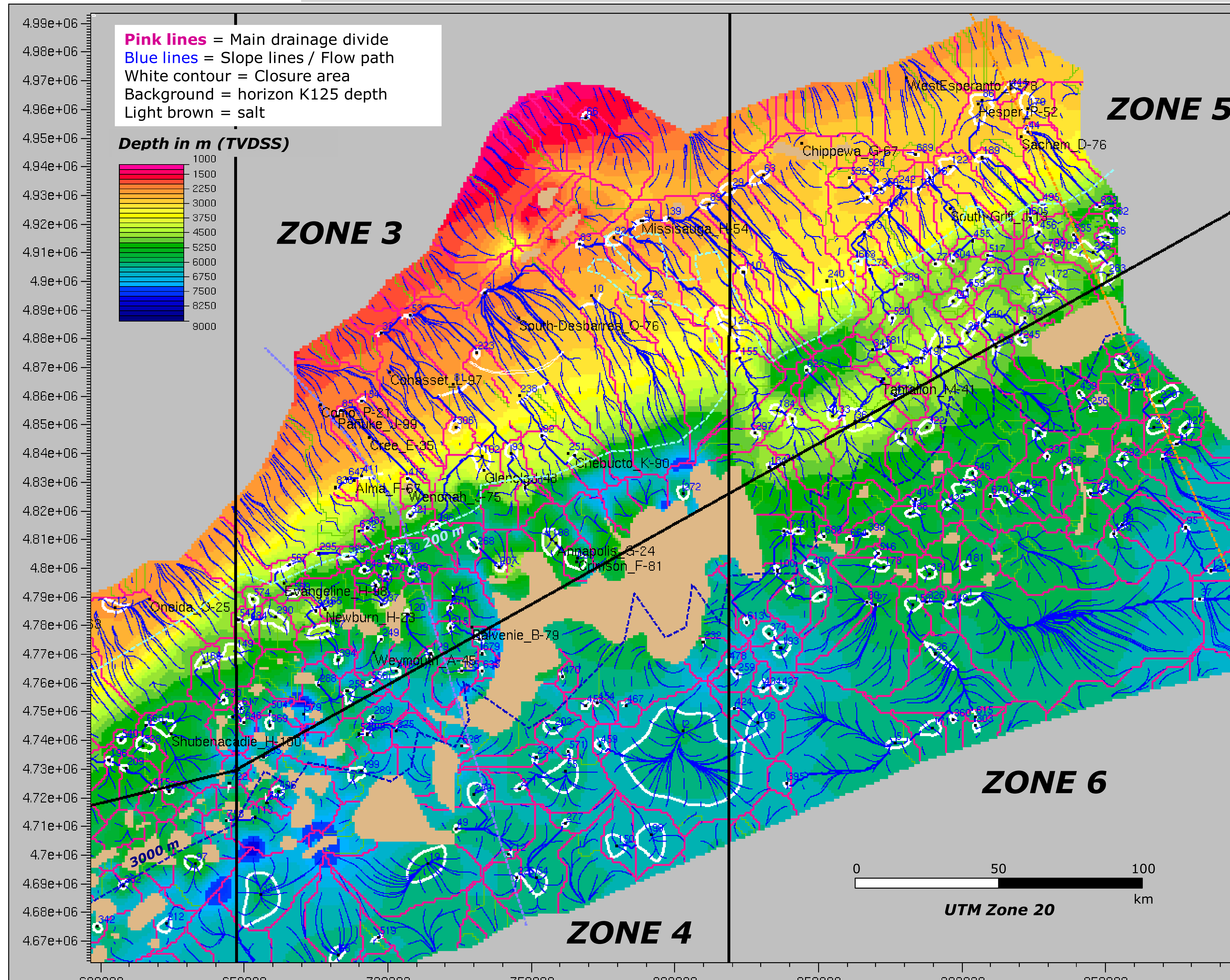
PLAY SYSTEMS
Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J163-J150)
Early-Middle-Jurassic (J200-J163)

Due to the complex shape of drainage areas in salt mini-basins (southern Zone 3, Zone 4), long-distance lateral migration is unlikely south of a line Evangeline-Annapolis.

However , relatively long distance lateral migration appears possible in the Sable Sub Basin, with mature SR in the deep depression between Evangeline, Annapolis, and Glenelg (North of the line Evangeline-Annapolis).

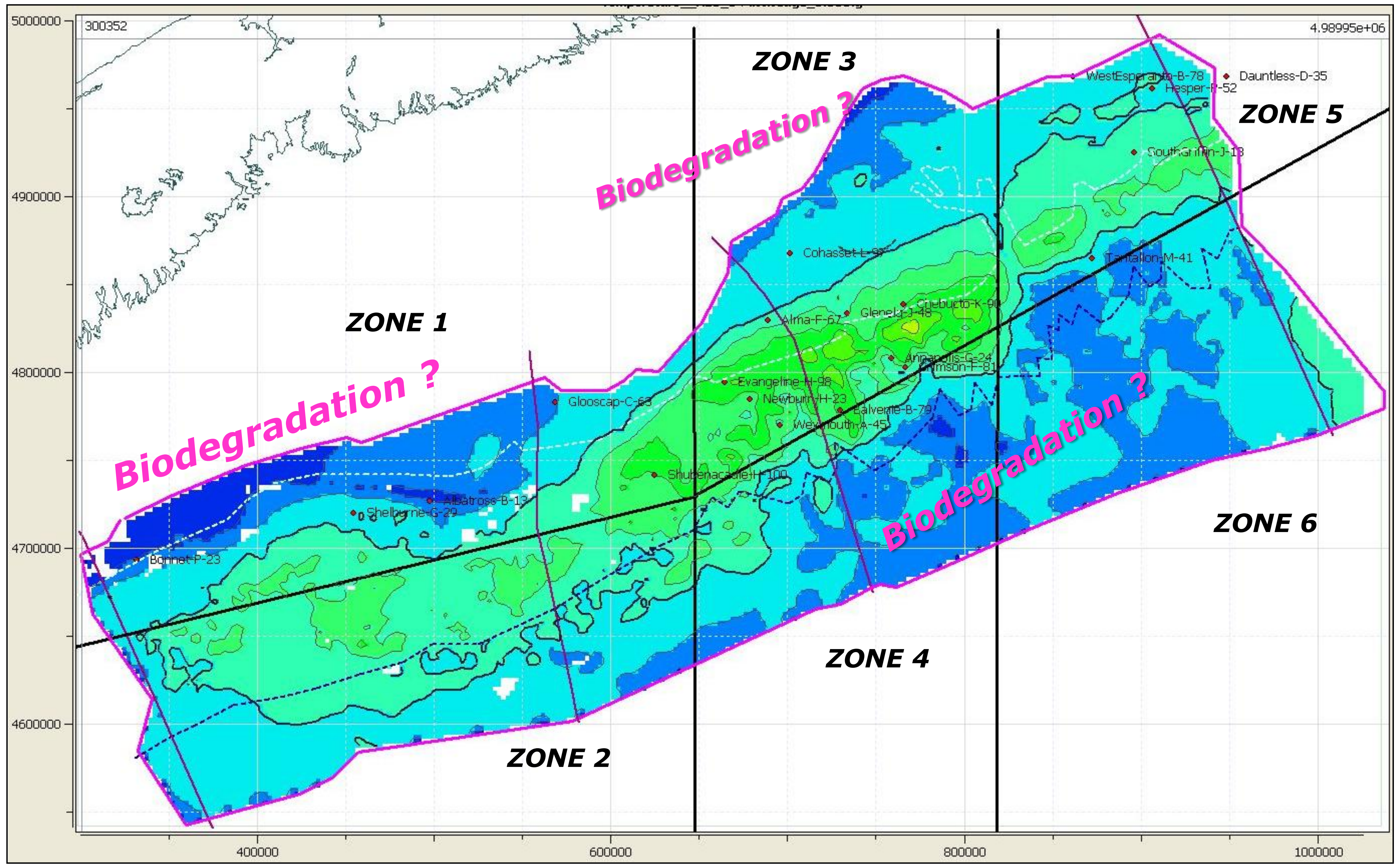
Potential migration pathways are longer in the upper slope and on the platform (zones 3 and 5). Very long horizontal migration pathways are also possible in the deep basin (southern zones 4 and 6)

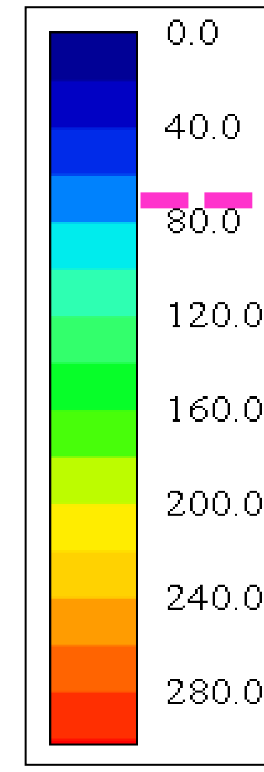
Hauterivian-Barremian – NE



Modeling Results Confidence

- 1
- 2
- 3
- 4
- 5





Biodegradation risk below 80 – 60 °C

°C
Temperature at K125

TEMPERATURE / BIODEGRADATION / SECONDARY CRACKING

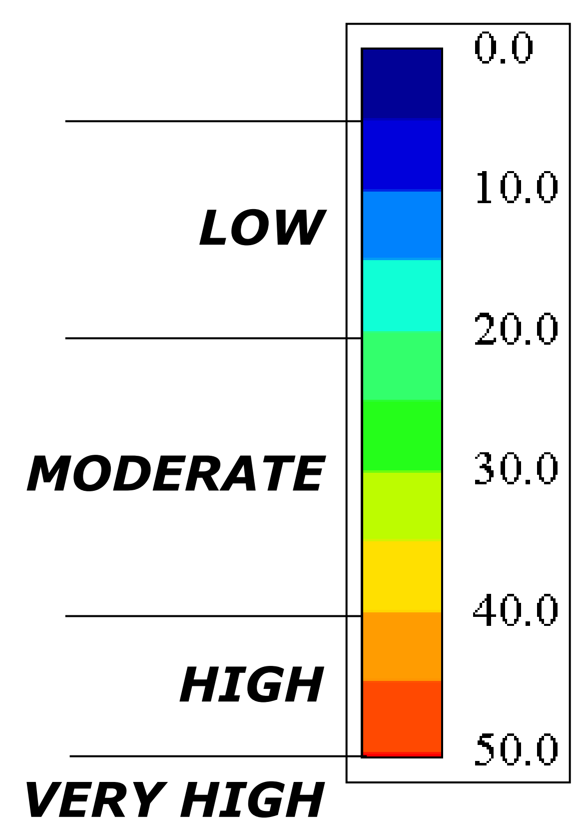
Temperature reaches a maximum of 180°C along the shelf break in Zone 3. A temperature higher than 100°C is usually observed in the slope zone.

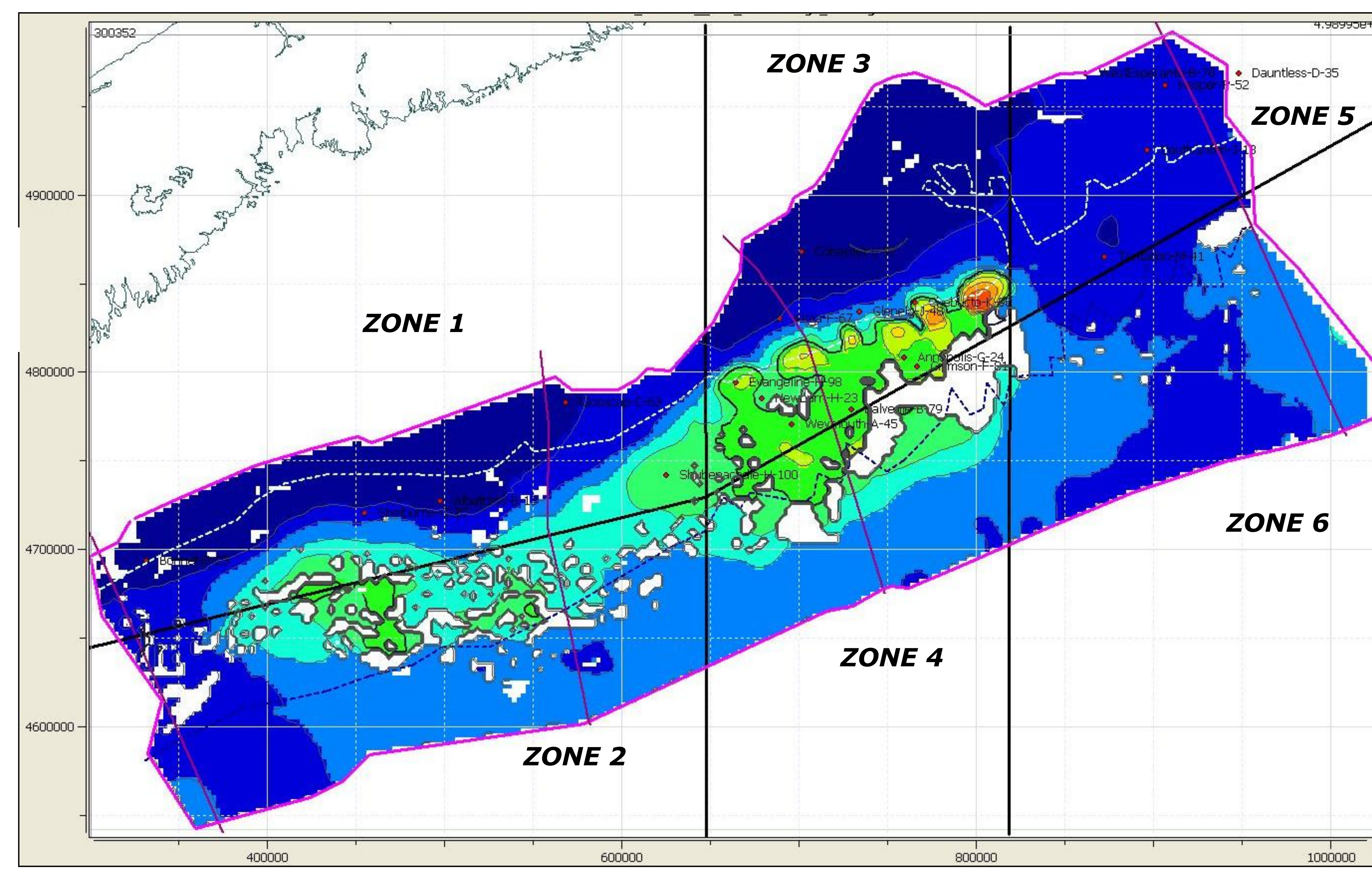
Risk of biodegradation exists on the platform, particularly in zones 1 and 3 (minimum temperature around 50°C in Zone 1). The risk is more limited in some areas of the deep basin, particularly in zones 4 and 6.

The possibility of secondary cracking exists in the deepest part of the basin, and only concerns the heaviest hydrocarbon fraction.

Hauterivian-Barremian Play System

MPa
Overpressure at K125





PRESSURE / OVERPRESSURE

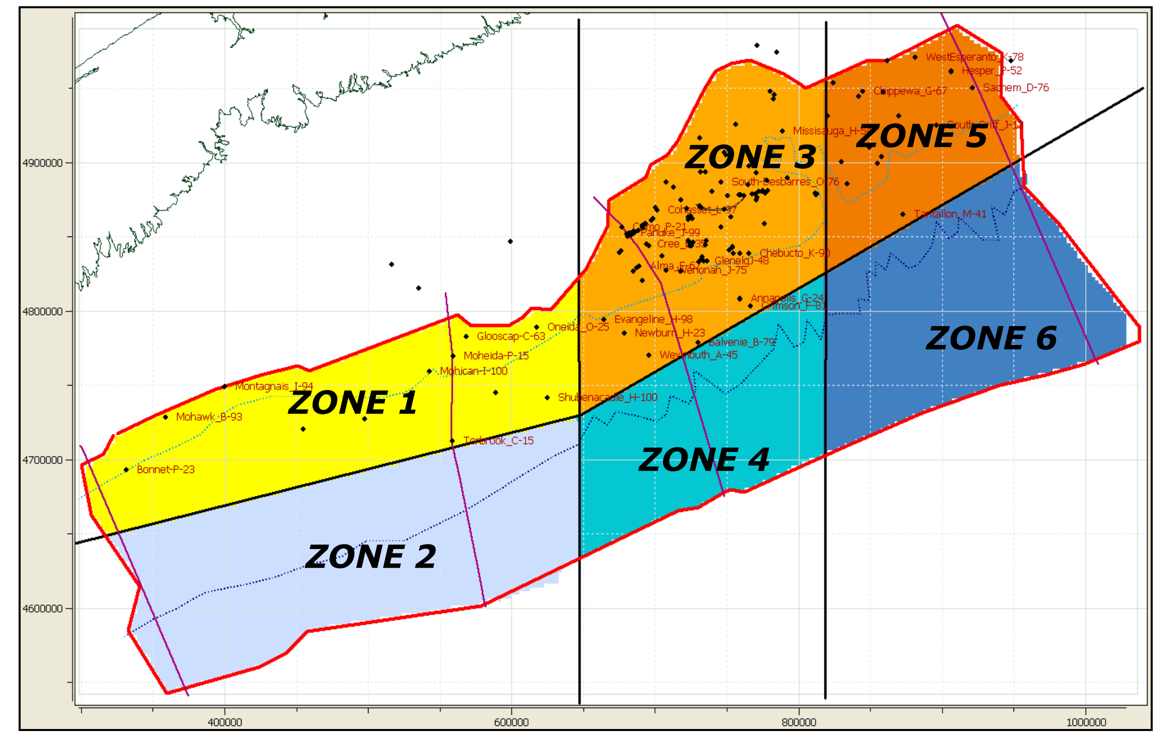
Overpressure is moderate in the slope along the shelf break, between zones 1 and 2, and between zones 3 and 4. Locally overpressure reaches very high values in the Zone 3, with highest values close to 50 MPa .

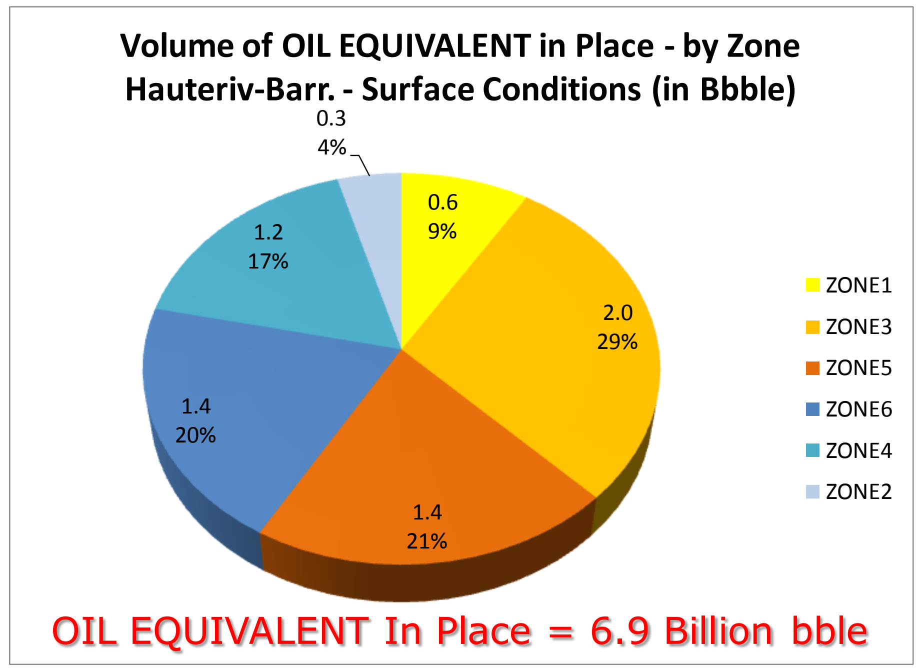
There is no overpressure on the platform (except maybe in Zone 5 and in southern Zone 3).

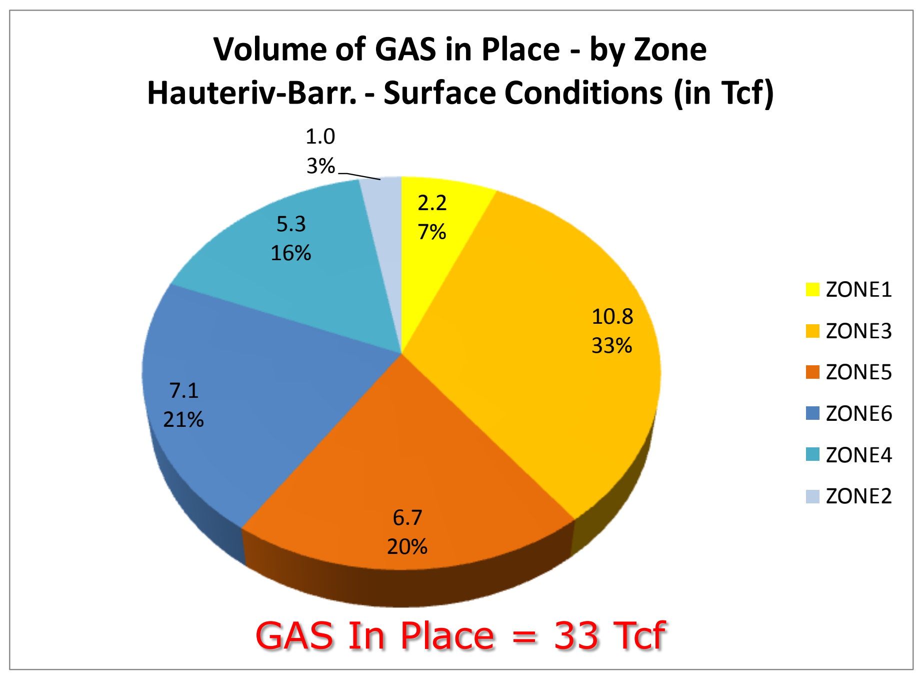
There is a low overpressure field in the deep basin (around 10 MPa, mainly in zones 2 and 4).

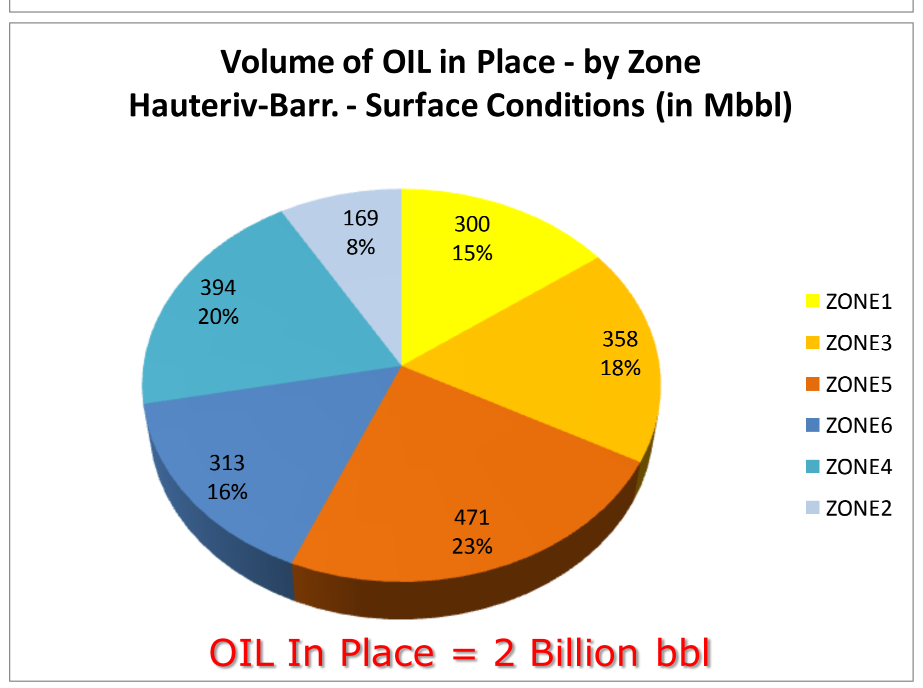
 Play System Modeling – Hauterivian-Barremian Sequence (K130-K123) – Temperature and Overpressure

Hauterivian-Barremian Play System



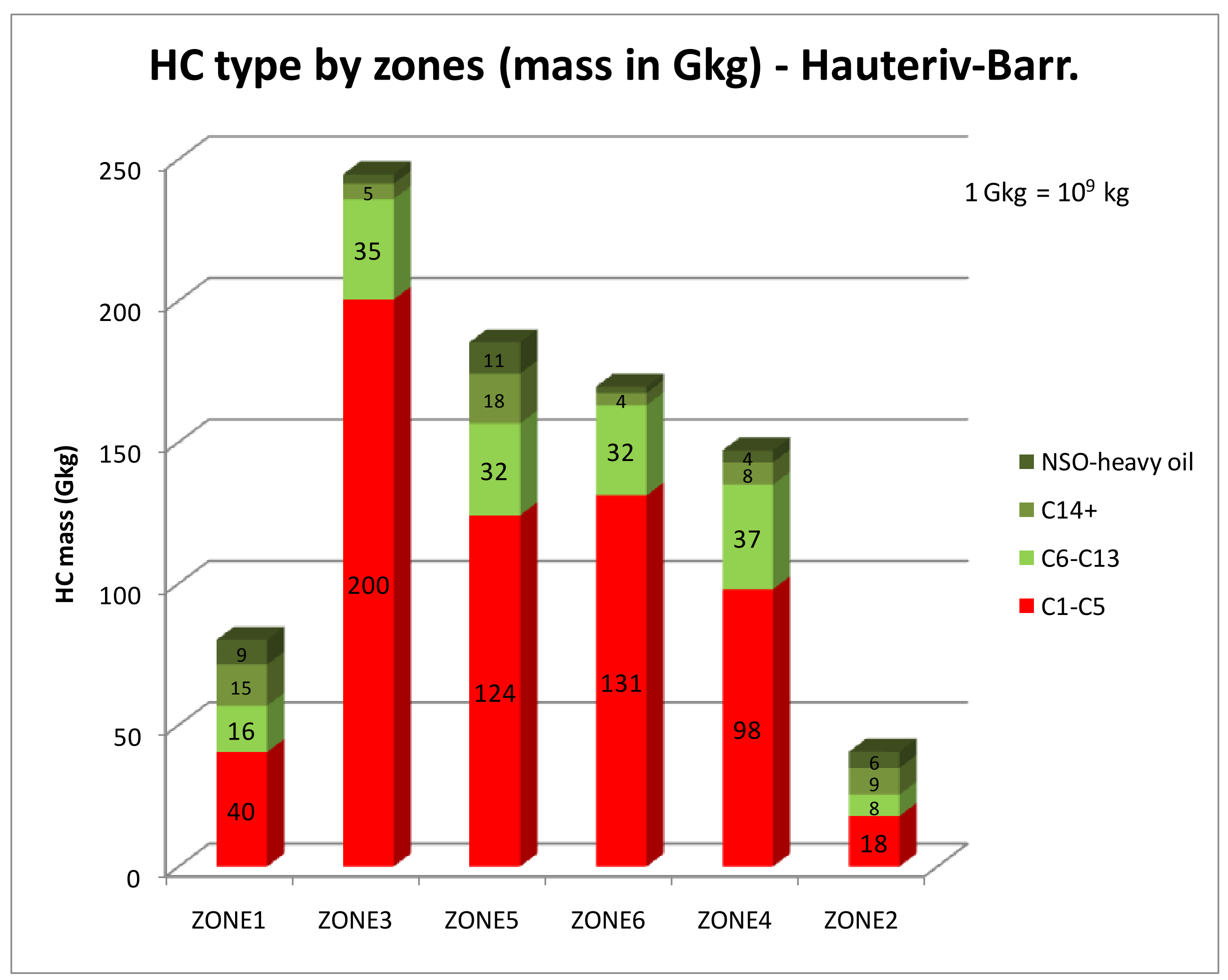






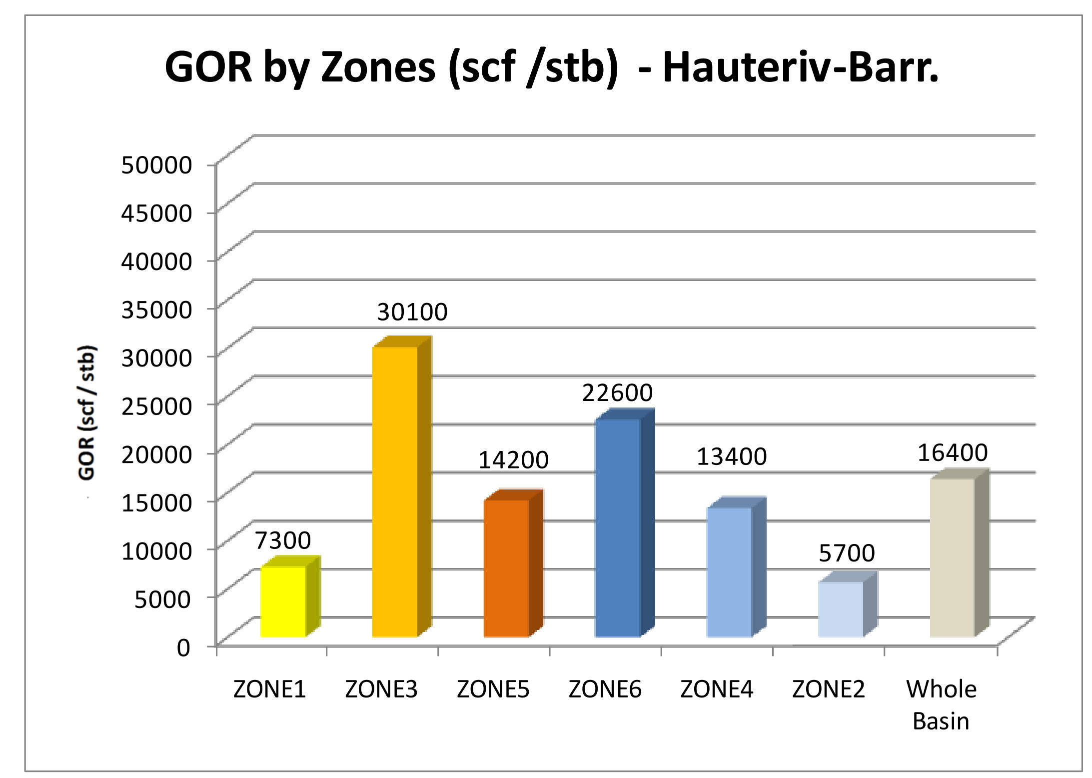
HC Repartition

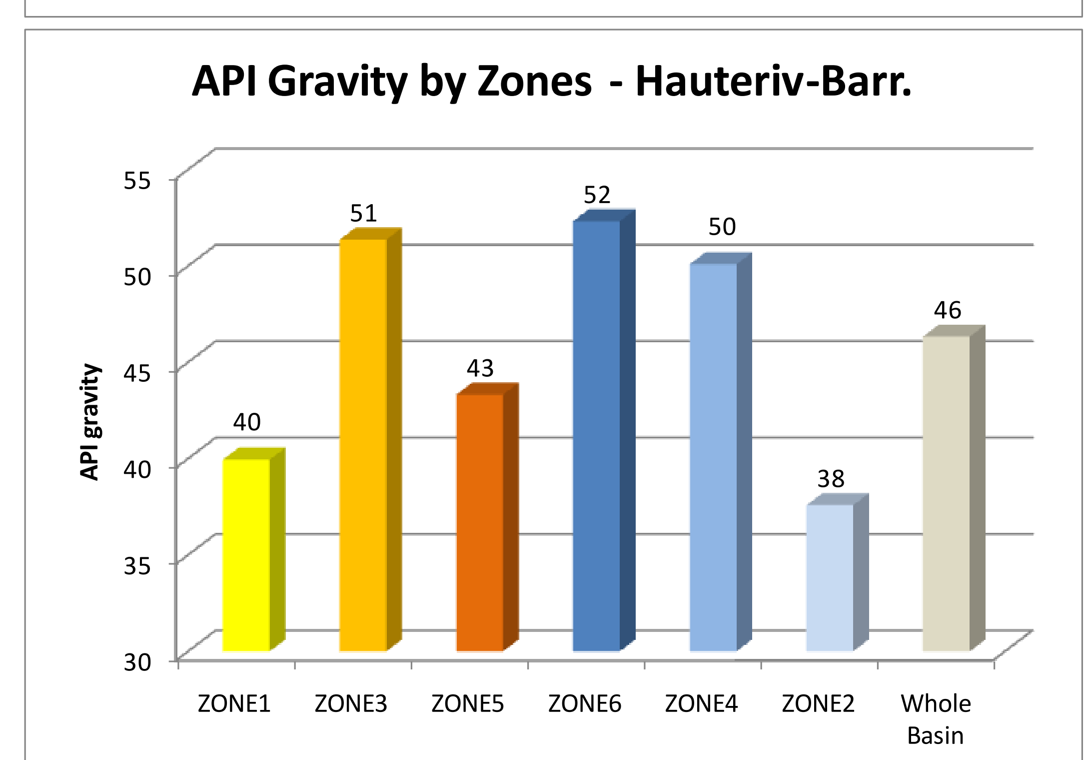
(masses and volumes – by Zone)

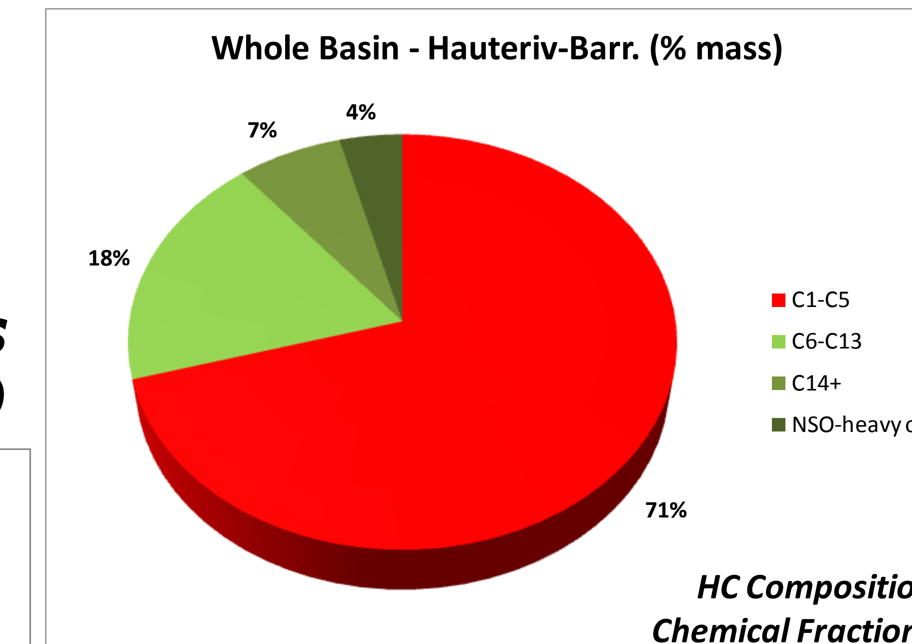


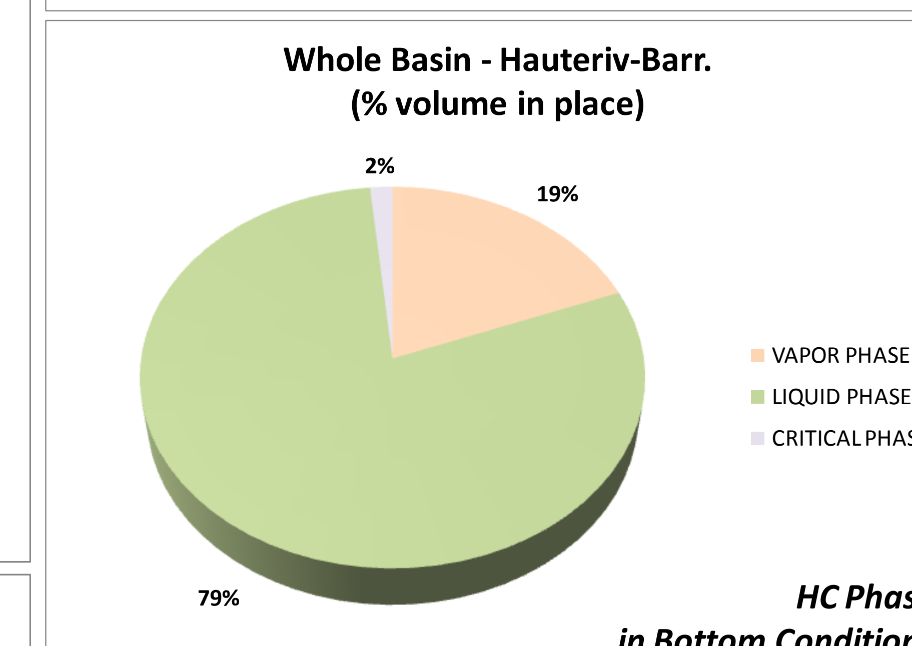
HC Characteristics

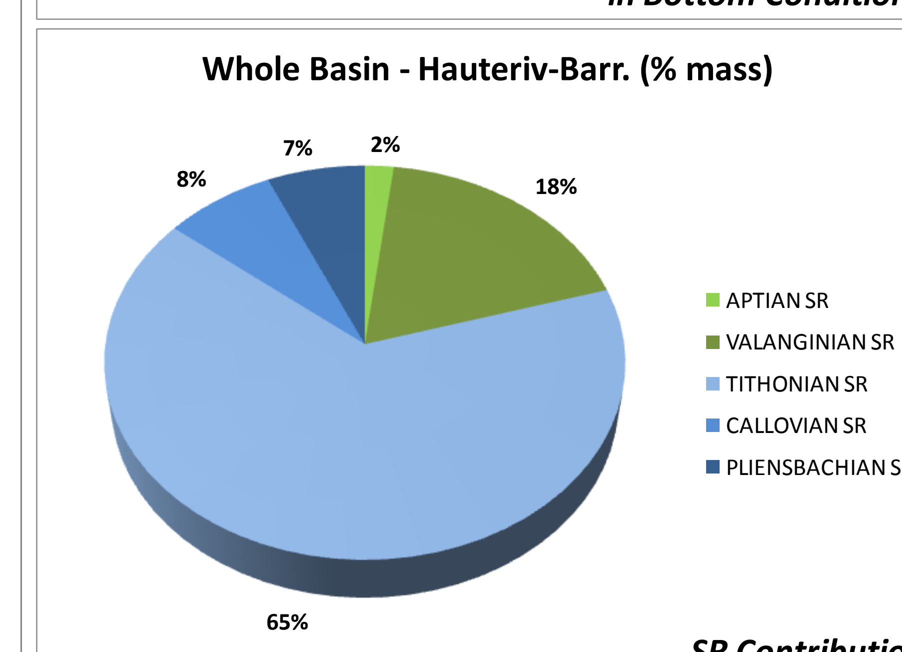
(Composition / Phase / Origin)



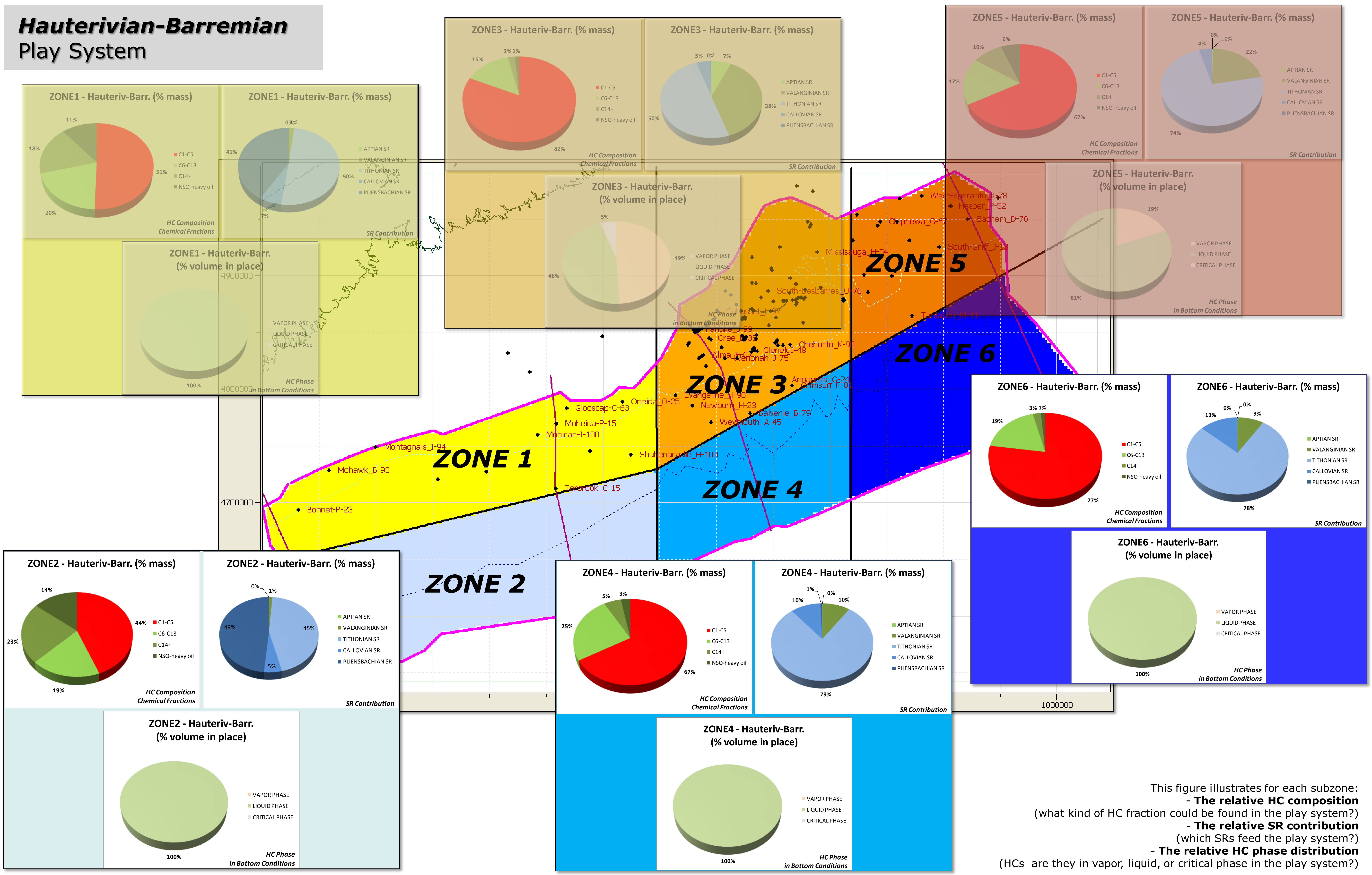




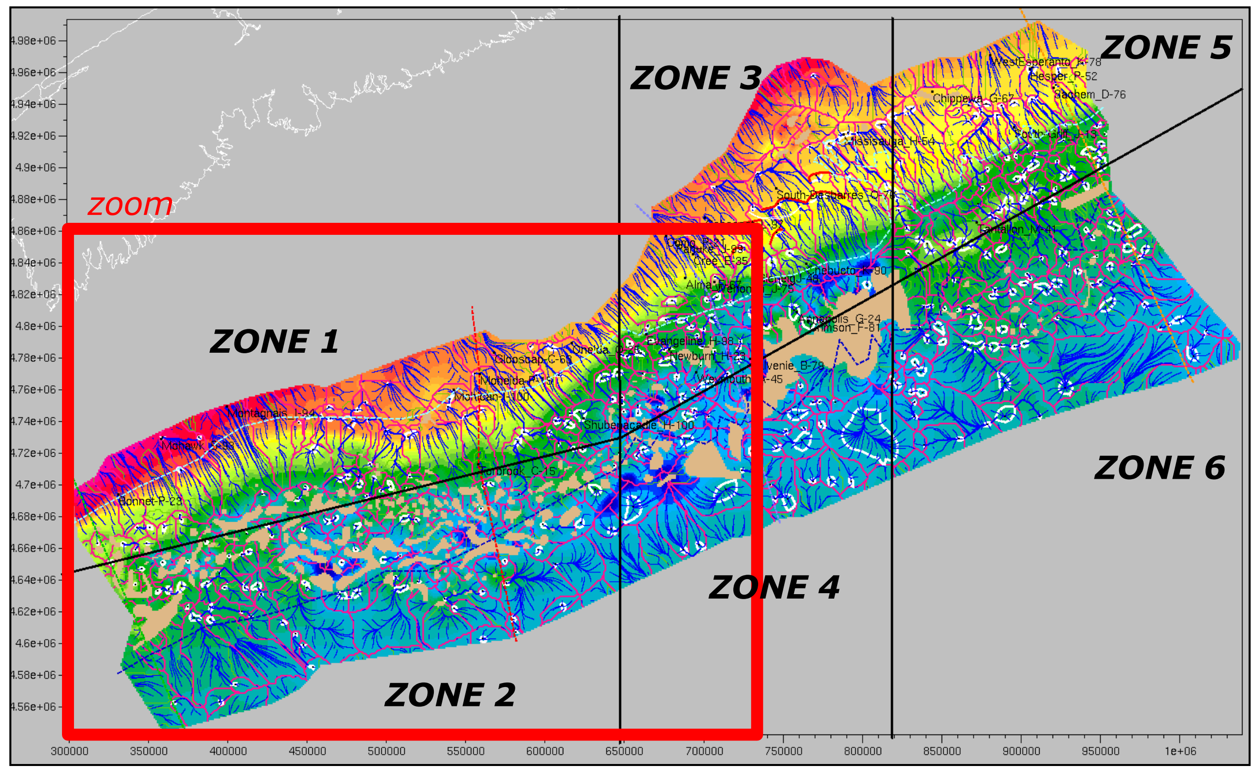




By ZONE Hauteriv-Barr.	*TOTAL GAS Mass (Gkg) In Place - Unrisked*	*TOTAL OIL mass (Gkg) In Place - Unrisked*	*TOTAL HC mass (Gkg) In Place - Unrisked*	*TOTAL GAS volume in surface (Tcf) In Place - Unrisked*	*TOTAL OIL volume in surface (Mbbl) In Place - Unrisked*	*TOTAL OIL EQUIVALENT volume in surface (Million bble) In Place - Unrisked*
ZONE1	40	40	80	**2.2**	**300**	**600**
ZONE3	200	44	245	**10.8**	**360**	**2000**
ZONE5	124	61	185	**6.7**	**470**	**1400**
ZONE6	131	38	170	**7.1**	**310**	**1400**
ZONE4	98	49	147	**5.3**	**390**	**1200**
ZONE2	18	23	41	**1.0**	**170**	**300**
Whole Basin	**612**	**255**	**867**	**33**	**2000**	**6900**



This figure illustrates for each subzone:
- **The relative HC composition**
(what kind of HC fraction could be found in the play system?)
- **The relative SR contribution**
(which SRs feed the play system?)
- **The relative HC phase distribution**
(HCs are they in vapor, liquid, or critical phase in the play system?)

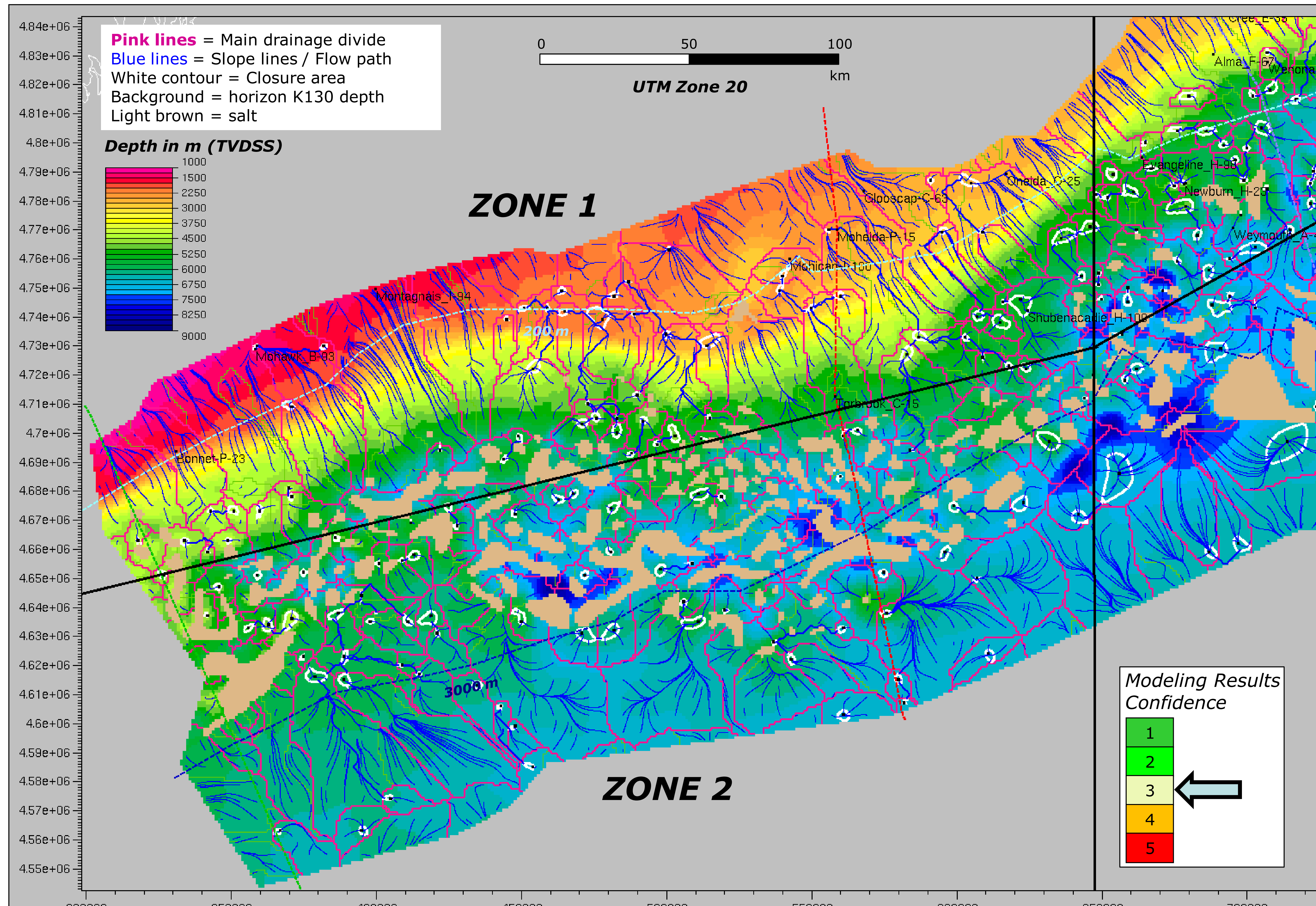


PLAY SYSTEMS
Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J163-J150)
Early-Middle-Jurassic (J200-J163)

Due to the complex shape of drainage areas in Zone 2 (salt mini-basins), long-distance lateral migration is unlikely in that part of the basin. Moreover the existence of relatively permeable faults along active salt bodies would increase the vertical migration, and so the hydrocarbon "leakage" out of this play (presence of seeps in this area). As a consequence potential mature SR in Zone 2 can hardly feed reservoirs in Zone 1. Potential migration pathways are longer in the upper slope and on the platform (Zone 1).

Berriasian-Valanginian-Hauterivian – SW

Zone	Zone Total Surface (km^2)	Number of Traps (trap surface > 2 km^2)	Number of Traps per 1000 km^2	Total Closed Areas in km^2 (sum of traps surface if surface > 2 km^2)	% Closed Areas (/ zone total surface)	Average Drainage Area Surface in km^2	Total Closed Porous Volume in Mm^3 (sum of traps volume)	Total Closed Porous Volume in Billion bbl (sum of traps volume)
Whole Basin	**141963**	**367**	**2.6**	**4840**	**3%**	**230**	**12700**	**80**
ZONE 1	26806	60	2.2	430	2%	230	700	4
ZONE 2	33263	75	2.3	570	2%	220	400	3
ZONE 3	24769	67	2.7	670	3%	220	2200	14
ZONE 4	18250	34	1.9	1470	8%	280	2100	13
ZONE 5	14694	56	3.8	500	3%	190	3900	25
ZONE 6	24181	76	3.1	1200	5%	260	3500	22



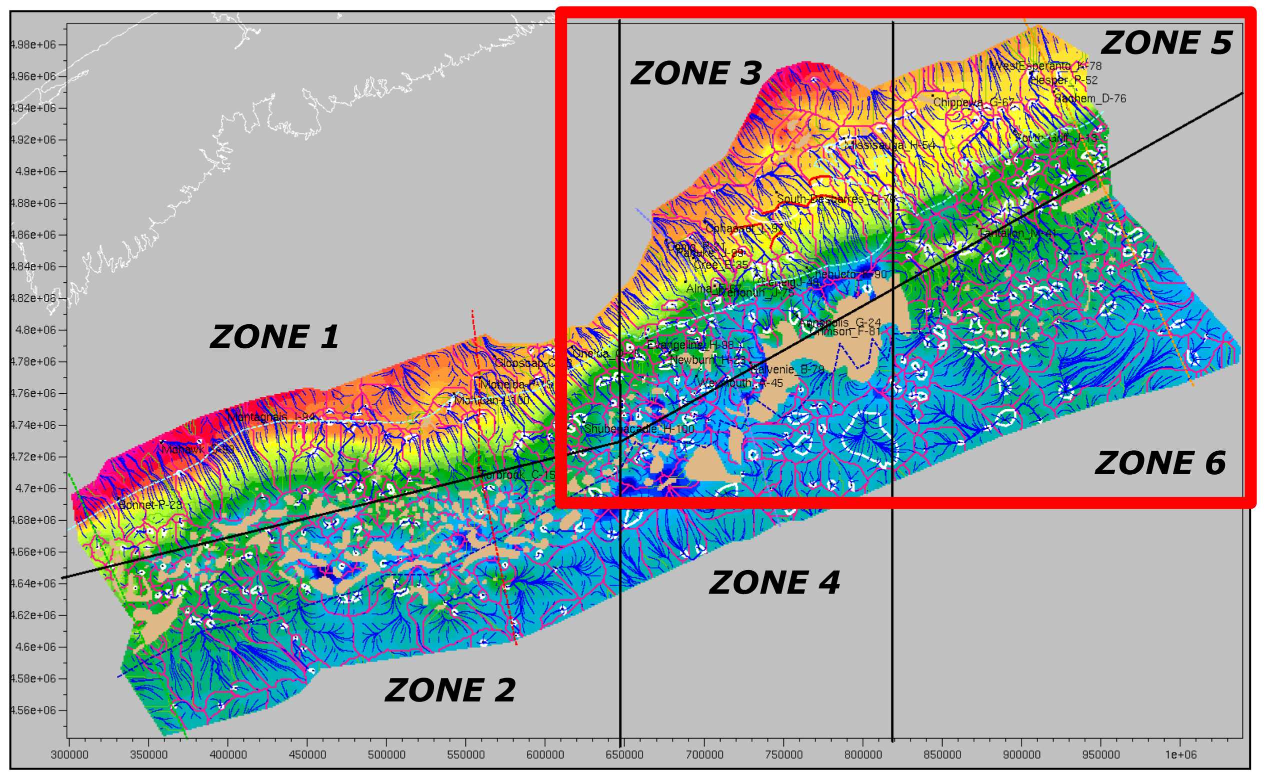
CLOSED AREAS / CLOSED POROUS VOLUMES / DRAINAGE AREAS

The **closed area** (or closure area) is defined by structural maps. It corresponds to the extend of a structural trap (4 way closure). About 2% of the study area is a closed area. Closed areas evolves during the geological history due to structural evolutions.

The **closed porous volume** is the volume of voids in a structural trap. This volume can be filled with water or hydrocarbons. It usually decreases during the geological history due to the compaction. Porosity modeling is done by Temis®.

Each trap is associated to a **drainage area** defined by slope lines, impermeable lithologies, permeable faults. The size of the drainage area may impact the charge of the trap.

The **Berriasian-Valanginian-Hauterivian play system** mainly includes the Upper Mississauga Formation Play and the Lower Mississauga Formation Play.

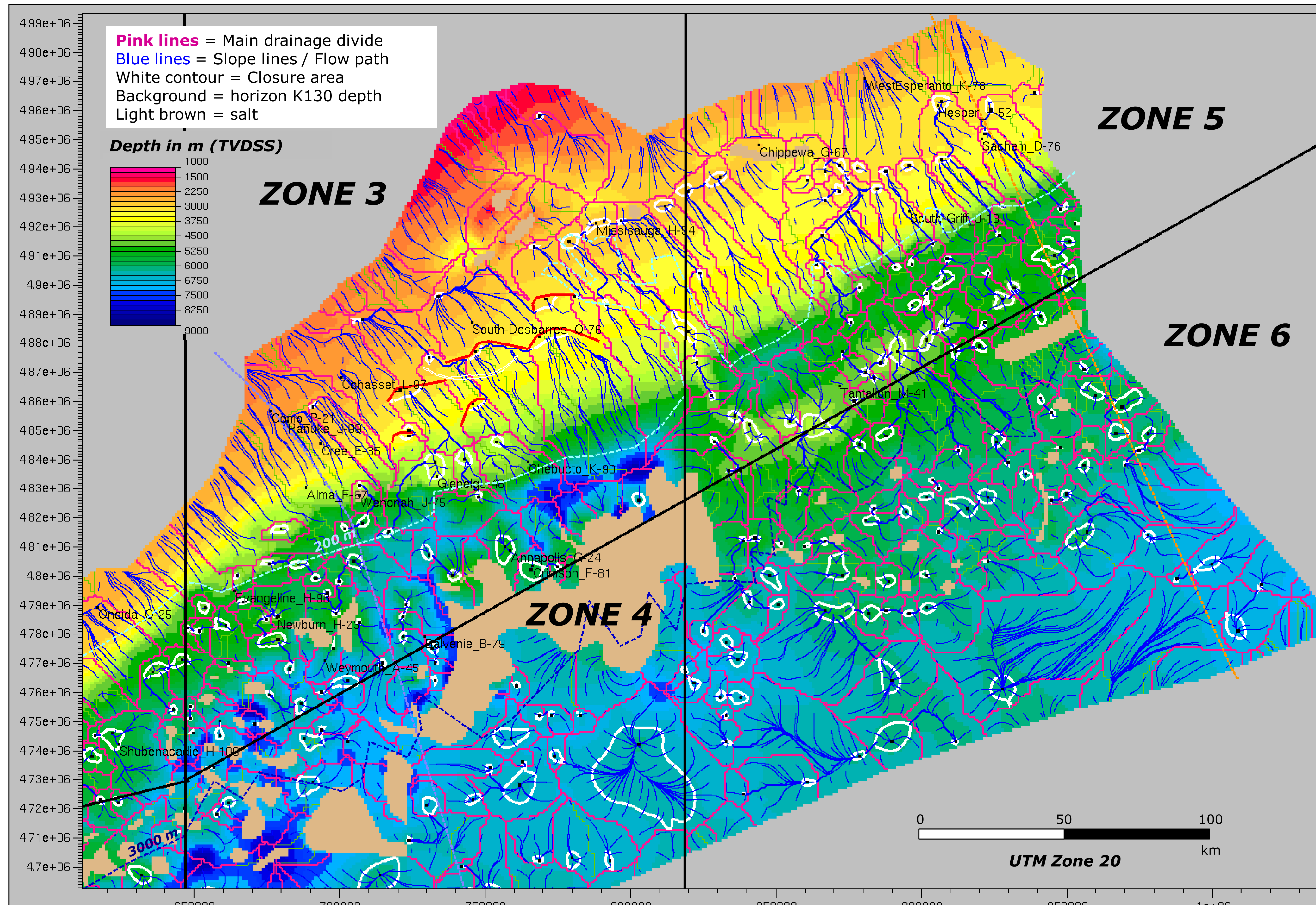


PLAY SYSTEMS
Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J163-J150)
Early-Middle-Jurassic (J200-J163)

Due to the complex shape of drainage areas in salt mini-basins (southern Zone 3, Zone 4), long-distance lateral migration is unlikely south of a line Evangeline-Annapolis-Tantallon. However this does not disturb petroleum systems in the Sable Sub Basin (Zone 3) because the most mature SRs are found in the deep depression between Evangeline, Annapolis, and Glenelg (north of the line Evangeline-Annapolis). Potential migration pathways are longer in the upper slope and on the platform (zones 3 and 5).

Very long horizontal migration pathways are also possible in the deep basin (southern zones 4 and 6).

Berriasian-Valanginian-Hauterivian – NE



Modeling Results Confidence

1
2
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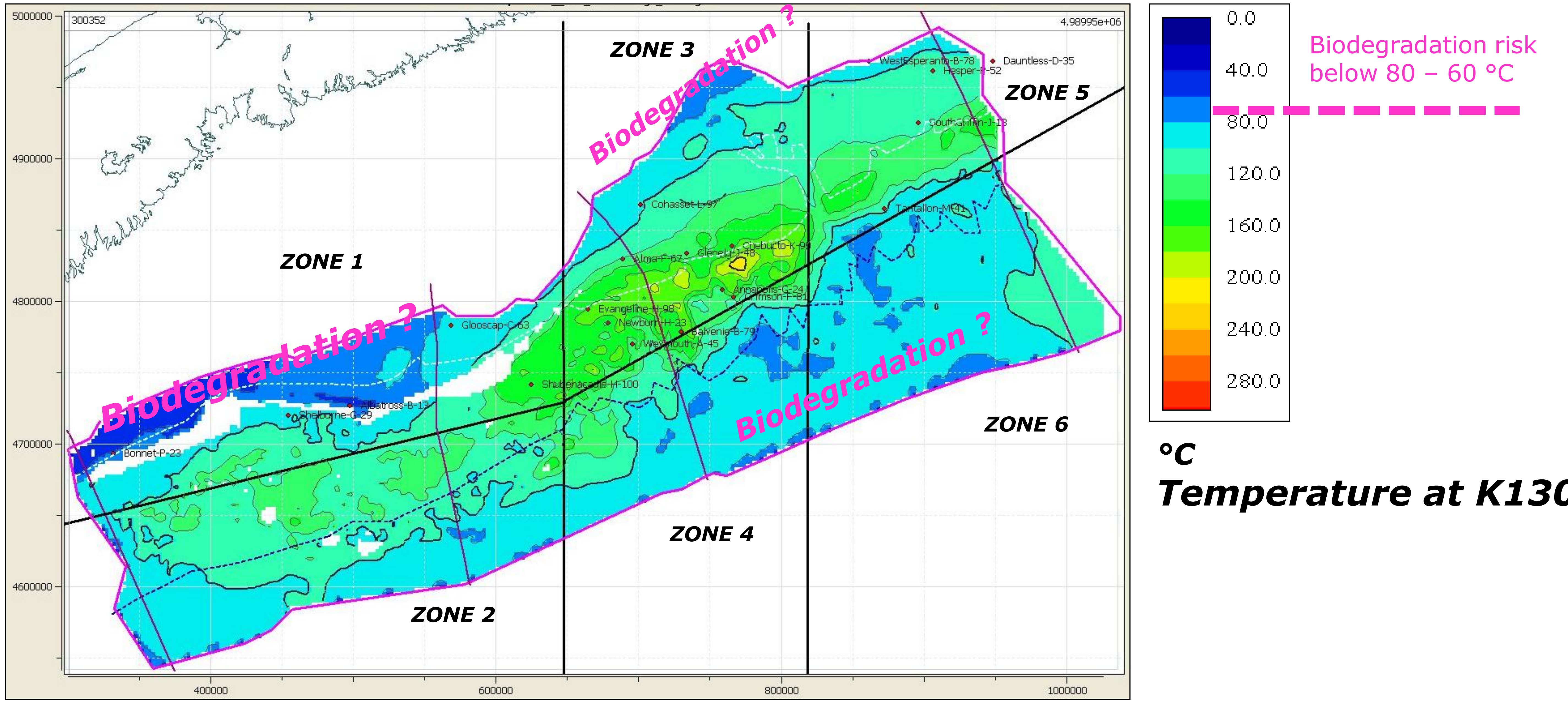


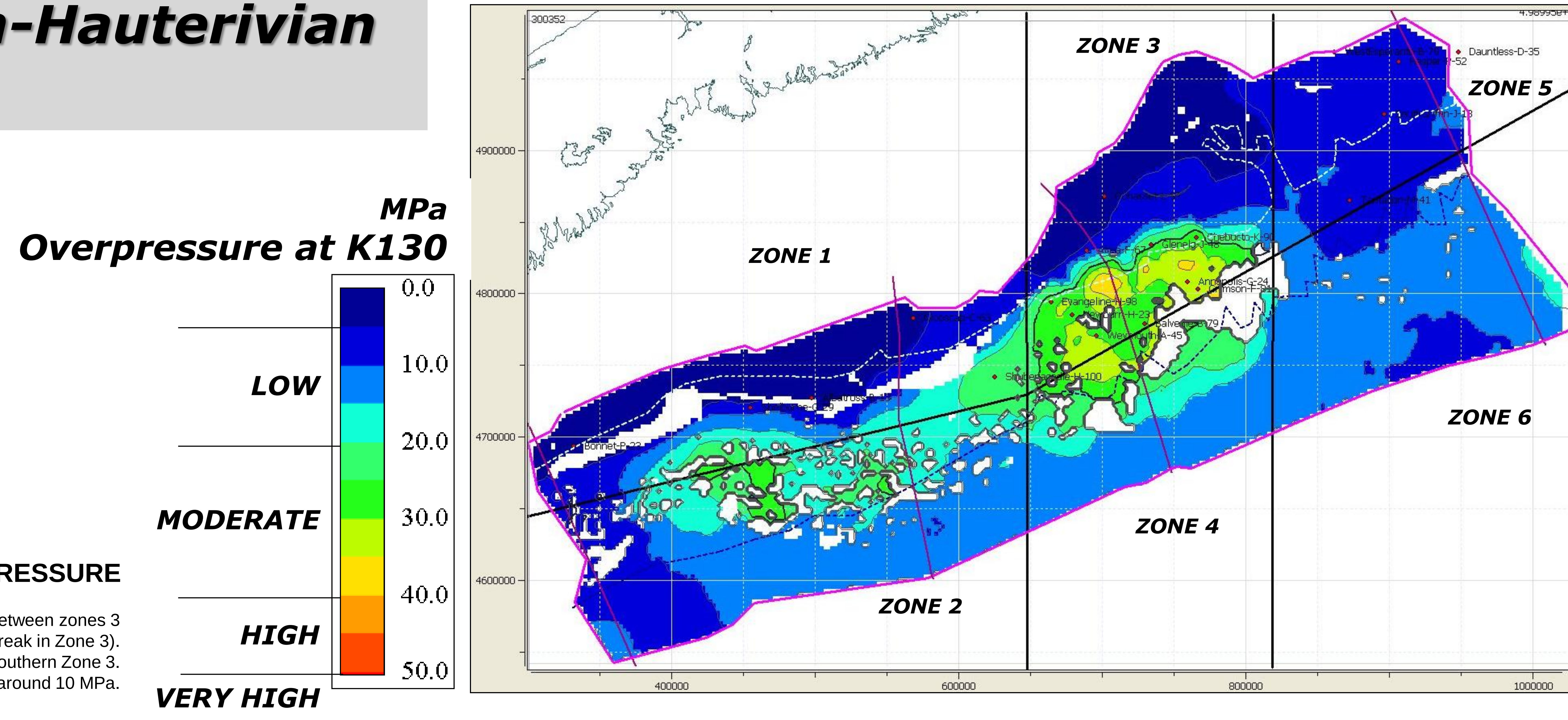
TEMPERATURE / BIODEGRADATION / SECONDARY CRACKING

Temperature locally reaches a maximum of 200°C in the slope along the shelf break in zone 3. Temperature reaches 140°C in Zone 5, 120 °C in zones 1 and 2, always in the slope zone.

Risk of biodegradation exists on the platform, mainly in Zone 1 (minimum temperature around 50°C). Temperature is close to 80°C on the platform of Zone 3, and in the deep basin of zones 4 and 6.

The possibility of secondary cracking exists in the deepest part of the basin, and only concerns the heaviest hydrocarbon fraction.

Berriasian-Valanginian-Hauterivian Play System

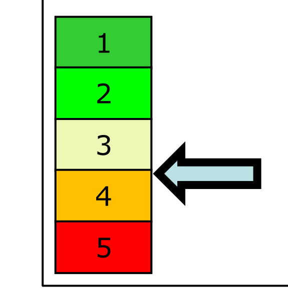


PRESSURE / OVERPRESSURE

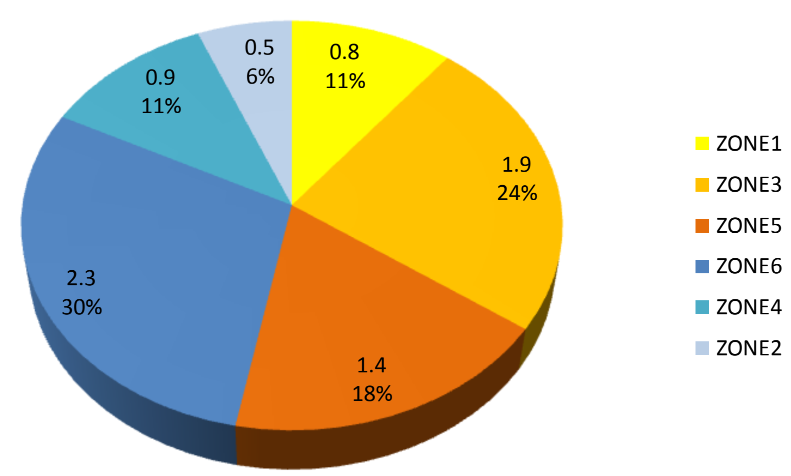
Overpressure is moderate in the slope along the shelf break between zones 1 and 2. Between zones 3 and 4 overpressure reaches higher values, locally up to 40 MPa (along the shelf break in Zone 3). There is no overpressure on the platform, except maybe in Zone 5 and in southern Zone 3. There is a low overpressure field in the deep basin (zones 2, 4, 6), the average value is around 10 MPa.

Berriasian-Valanginian-Hauterivian Play System

Modeling Results Confidence

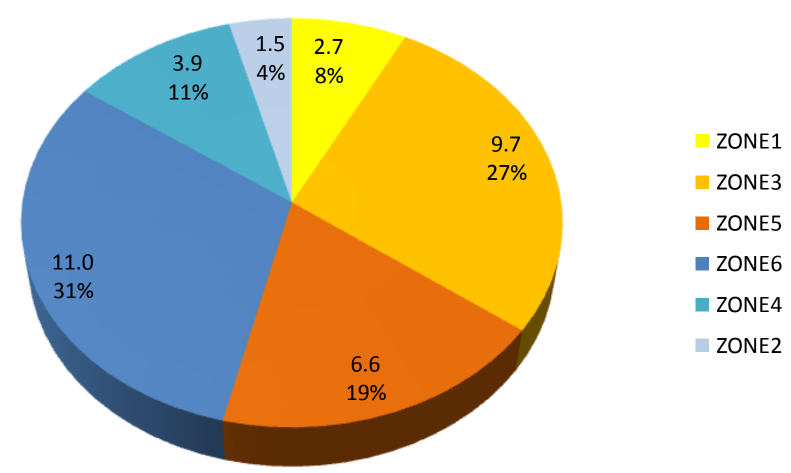


Volume of OIL EQUIVALENT in Place - by Zone
Berrias-Haut. - Surface Conditions (in Bbble)



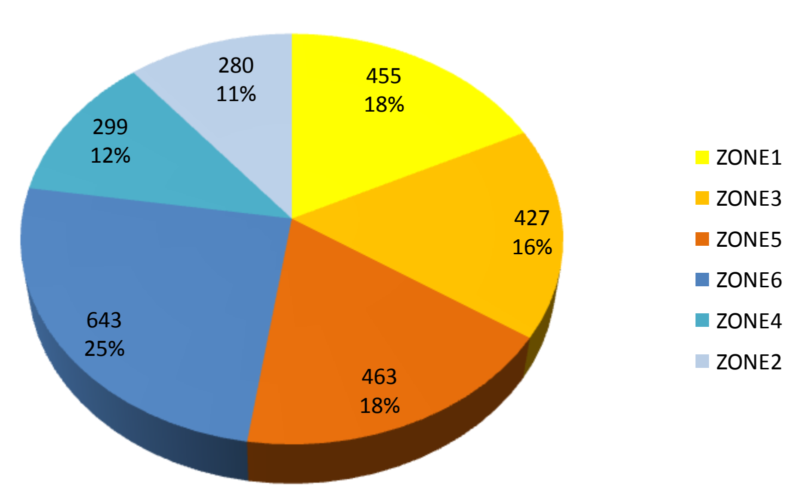
OIL EQUIVALENT In Place = 7.8 Billion bble

Volume of GAS in Place - by Zone
Berrias-Haut. - Surface Conditions (in Tcf)

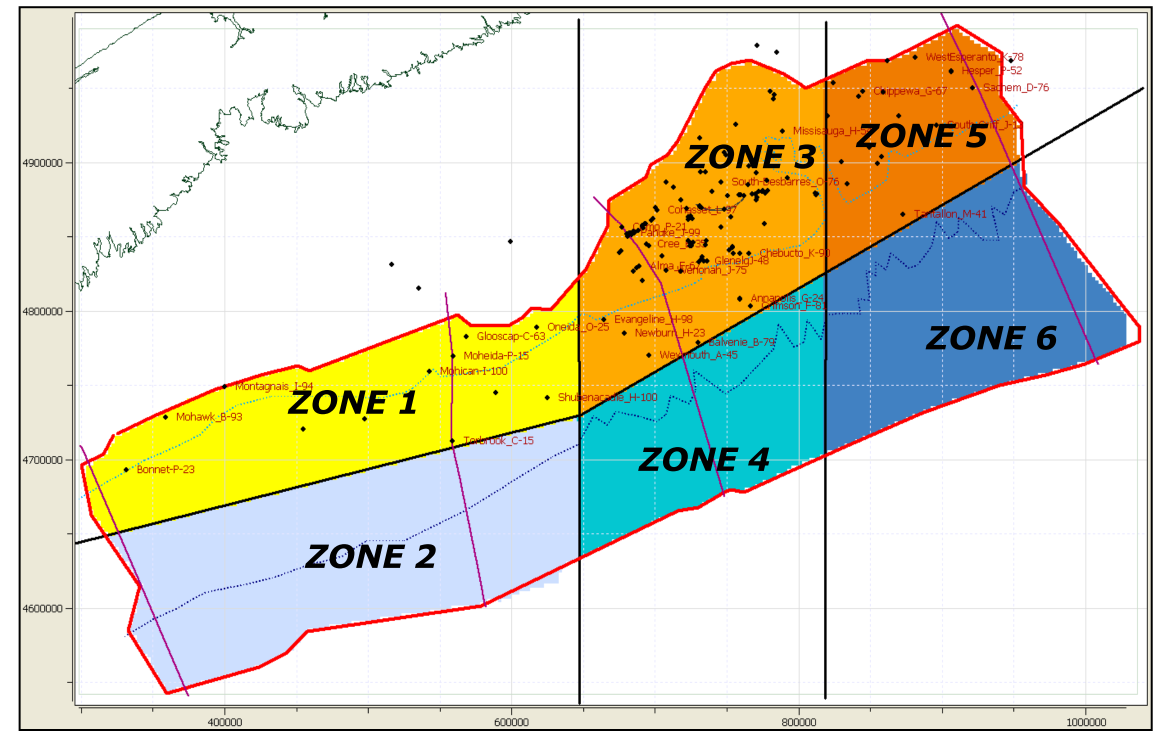


GAS In Place = 35 Tcf

Volume of OIL in Place - by Zone
Berrias-Haut. - Surface Conditions (in Mbbl)

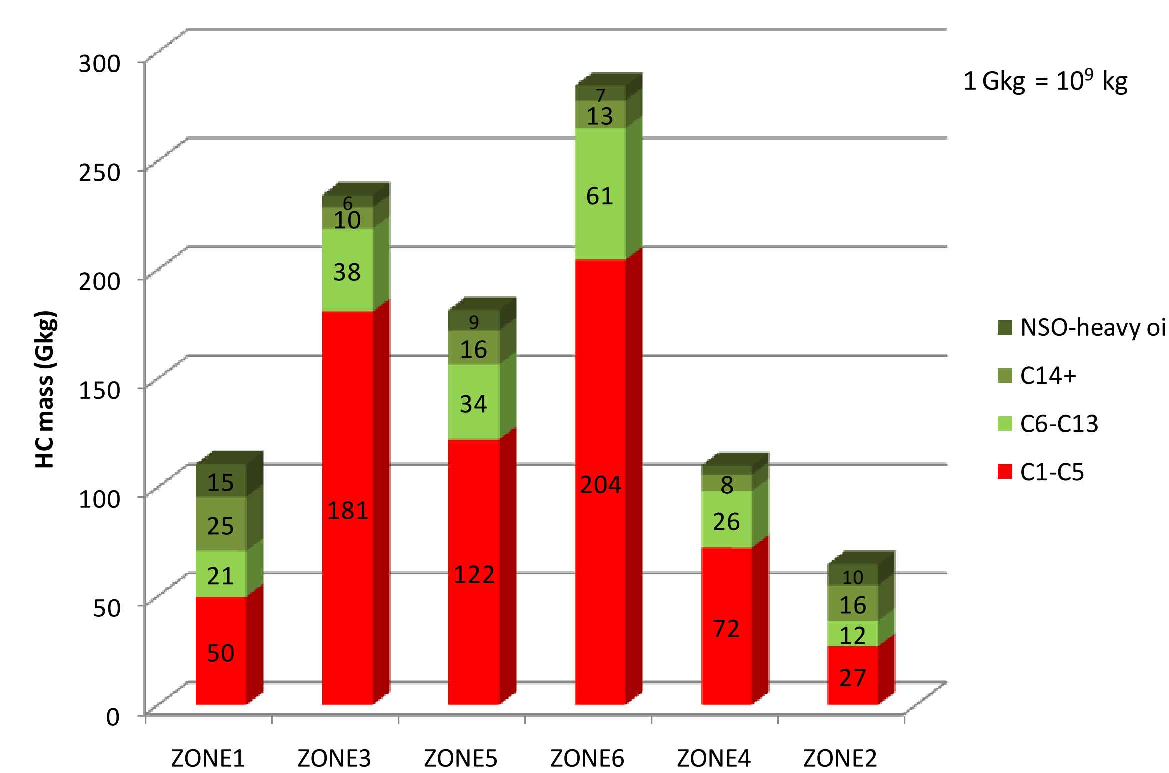


OIL In Place = 2.6 Billion bbl



HC Repartition
(masses and volumes – by Zone)

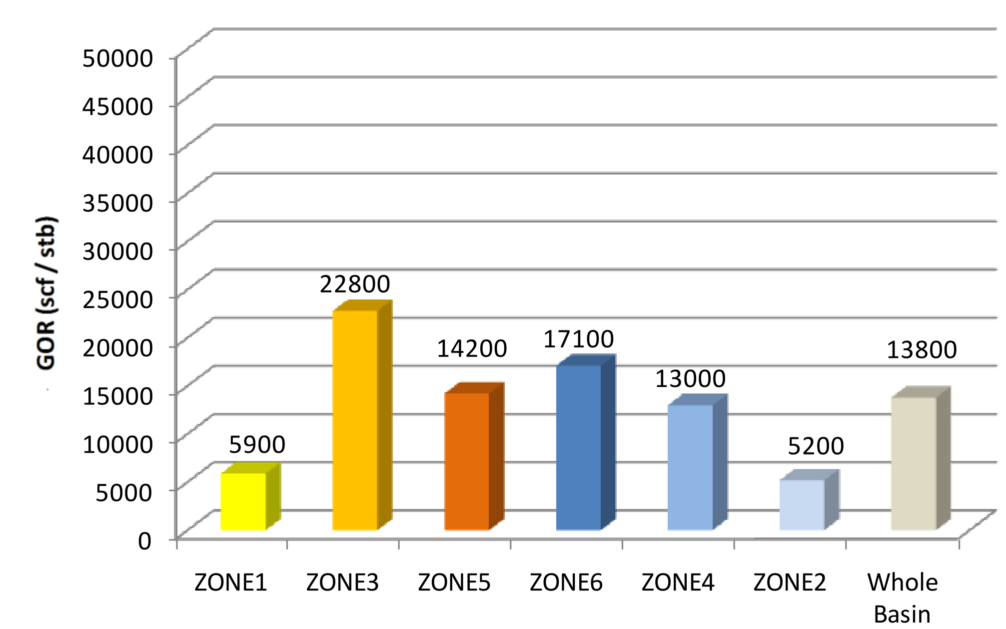
HC type by zones (mass in Gkg)
Berrias-Hauteriv.



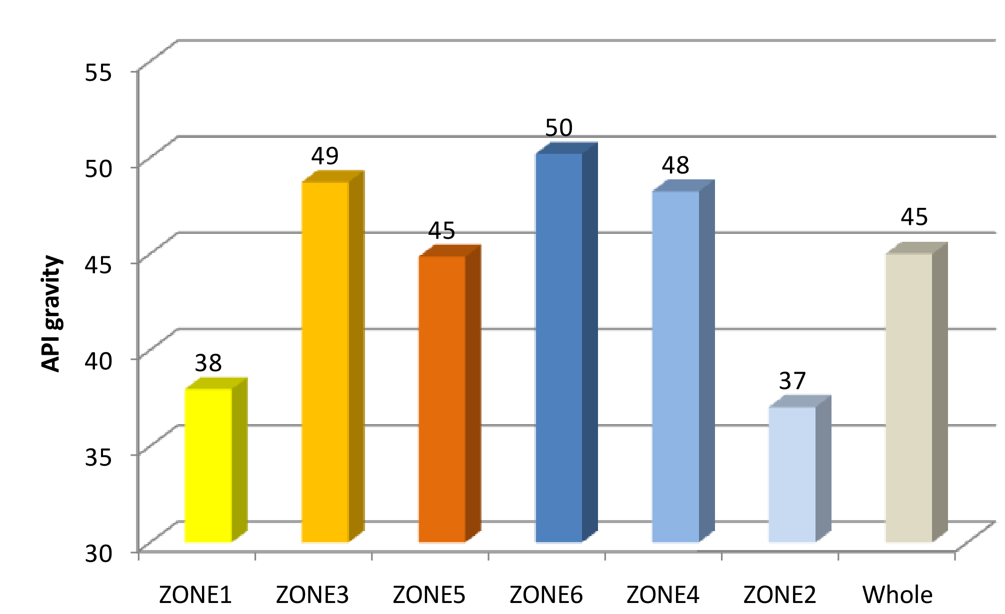
By ZONE Berrias-Haut.	TOTAL GAS Mass (Gkg) In Place - Unrisked	TOTAL OIL mass (Gkg) In Place - Unrisked	TOTAL HC mass (Gkg) In Place - Unrisked	TOTAL GAS volume in surface (Tcf) In Place - Unrisked	TOTAL OIL volume in surface (Mbbl) In Place - Unrisked	TOTAL OIL EQUIVALENT volume in surface (Million bble) In Place - Unrisked
ZONE1	50	61	111	2.7	450	800
ZONE3	181	54	234	9.7	430	1900
ZONE5	122	60	182	6.6	460	1400
ZONE6	204	80	285	11.0	640	2300
ZONE4	72	38	110	3.9	300	900
ZONE2	27	38	65	1.5	280	500
Whole Basin	656	330	986	35	2560	7800

HC Characteristics
(Composition / Phase / Origin)

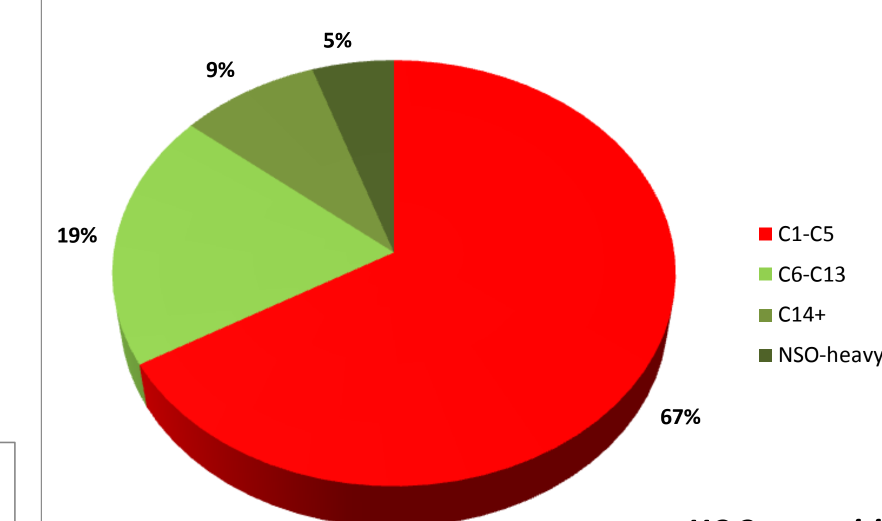
GOR by Zones (scf /stb) - Berrias-Haut.



API Gravity by Zones - Berrias-Haut.

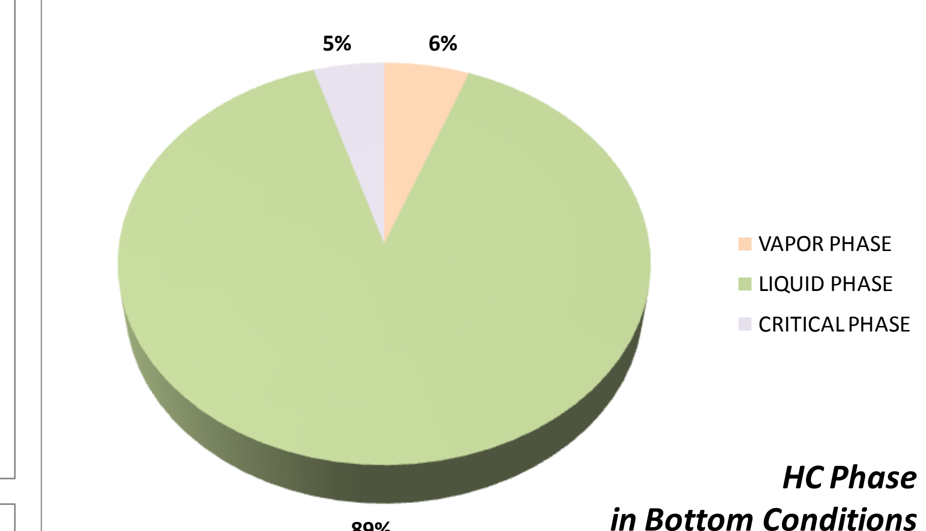


Whole Basin - Berrias-Haut. (% mass)



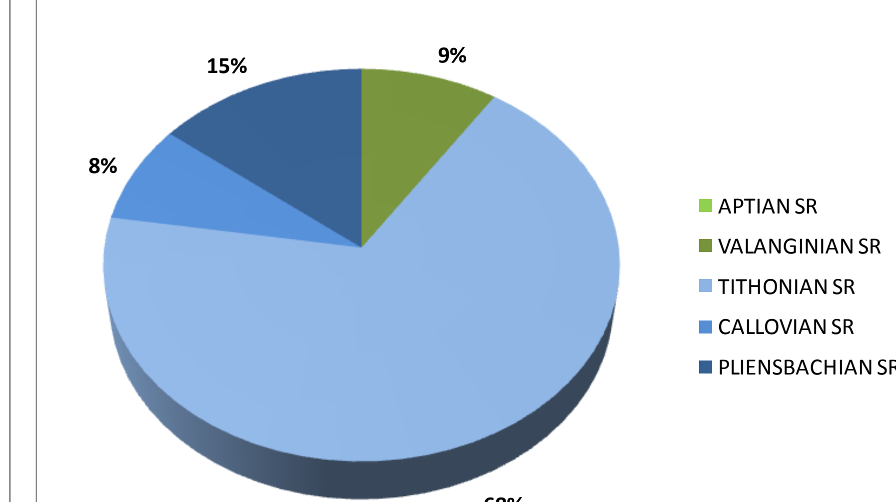
HC Composition
Chemical Fractions

Whole Basin - Berrias-Haut.
(% volume in place)



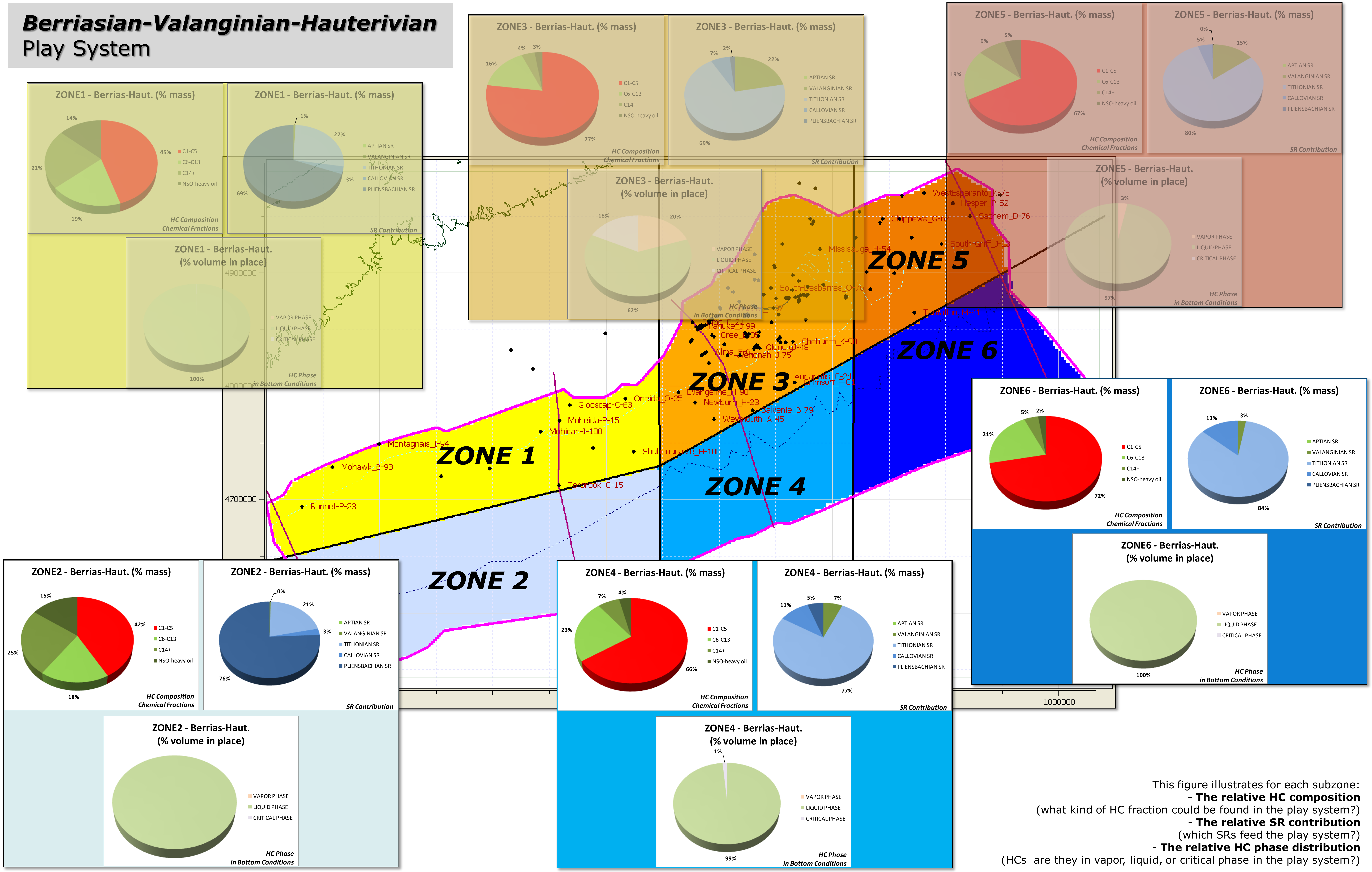
HC Phase
in Bottom Conditions

Whole Basin - Berrias-Haut. (% mass)

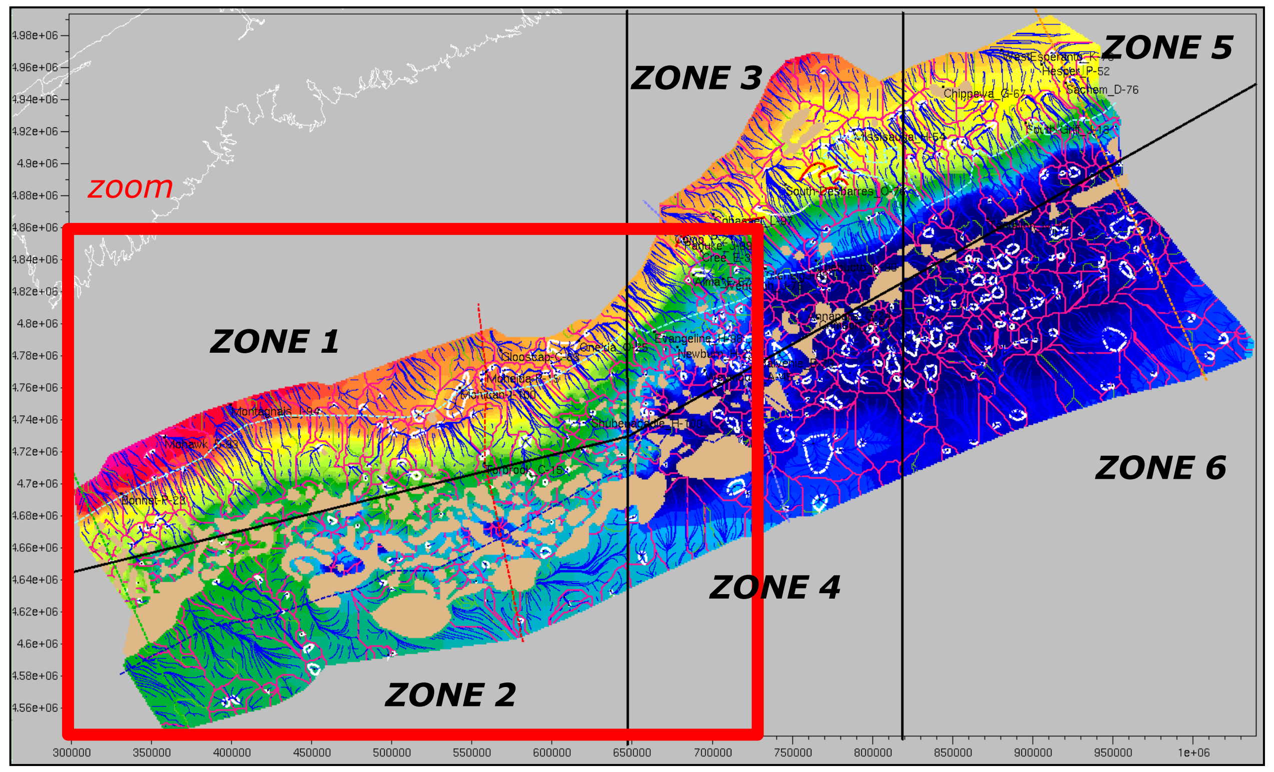


SR Contribution

Berriasian-Valanginian-Hauterivian Play System



This figure illustrates for each subzone:
- **The relative HC composition**
(what kind of HC fraction could be found in the play system?)
- **The relative SR contribution**
(which SRs feed the play system?)
- **The relative HC phase distribution**
(HCs are they in vapor, liquid, or critical phase in the play system?)



PLAY SYSTEMS
Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J163-J150)
Early-Middle-Jurassic (J200-J163)

Zone	Zone Total Surface (km^2)	Number of Traps (trap surface > 2 km^2)	Number of Traps per 1000 km^2	Total Closed Areas in km^2 (sum of traps surface if surface > 2 km^2)	% Closed Areas (/ zone total surface)	Average Drainage Area Surface in km^2	Total Closed Porous Volume in Mm^3 (sum of traps volume)	Total Closed Porous Volume in Billion bbl (sum of traps volume)
Whole Basin	141963	317	2.2	4310	3%	230	4200	26
ZONE 1	26806	52	1.9	700	3%	310	1900	12
ZONE 2	33263	44	1.3	270	1%	160	100	1
ZONE 3	24769	57	2.3	560	2%	220	700	4
ZONE 4	18250	50	2.7	1190	7%	220	400	3
ZONE 5	14694	33	2.2	270	2%	300	600	4
ZONE 6	24181	81	3.3	1340	6%	210	500	3

CLOSED AREAS / CLOSED POROUS VOLUMES / DRAINAGE AREAS

The **closed area** (or closure area) is defined by structural maps. It corresponds to the extend of a structural trap (4 way closure). About 2% of the study area is a closed area. Closed areas evolves during the geological history due to structural evolutions.

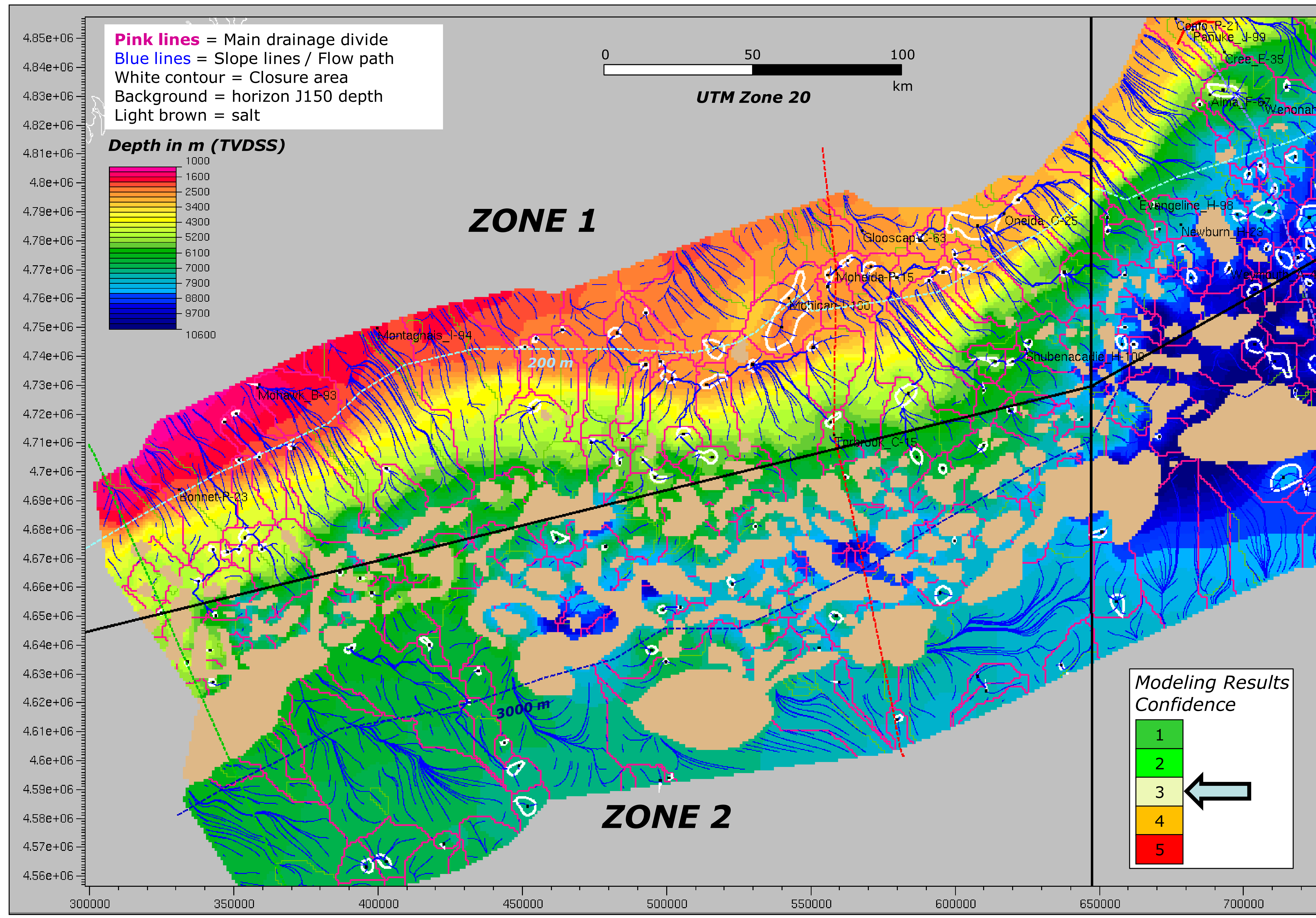
The **closed porous volume** is the volume of voids in a structural trap. This volume can be filled with water or hydrocarbons. It usually decreases during the geological history due to the compaction. Porosity modeling is done by Temis®.

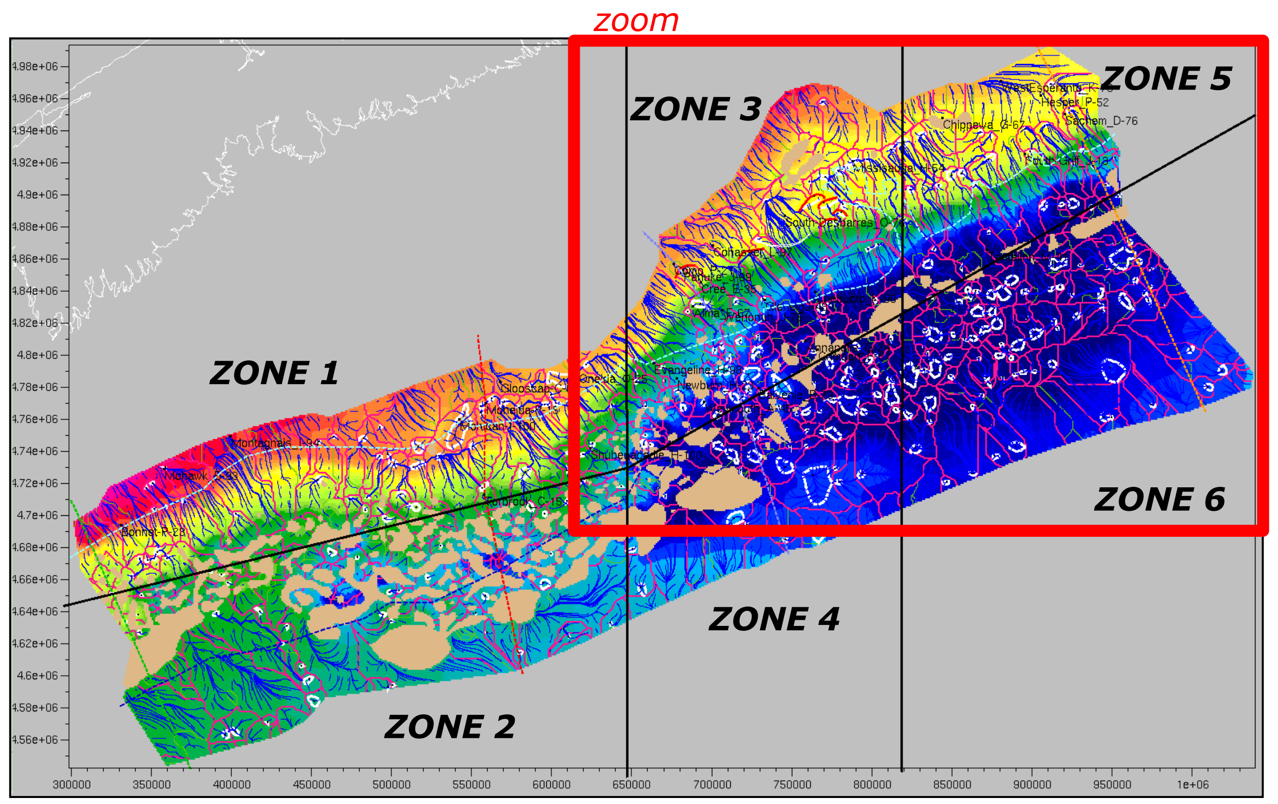
Each trap is associated to a **drainage area** defined by slope lines, impermeable lithologies, permeable faults. The size of the drainage area may impact the charge of the trap.

The **Oxfordian-Tithonian play system** includes: the Baccaro Formation Play, the MicMac Formation Play, etc.

Due to the complex shape of drainage areas in Zone 2 (salt mini-basins), long-distance lateral migration is unlikely in that part of the basin. Moreover the existence of relatively permeable faults along active salt bodies would increase the vertical migration, and so the hydrocarbon "leakage" out of this play (presence of seeps in this area).
As a consequence potential mature SR in Zone 2 can hardly feed reservoirs in Zone 1.
Potential migration pathways are longer in the upper slope and on the platform (Zone 1).
In Zone 1, traps seems bigger and more numerous eastward.

Oxfordian-Tithonian – SW

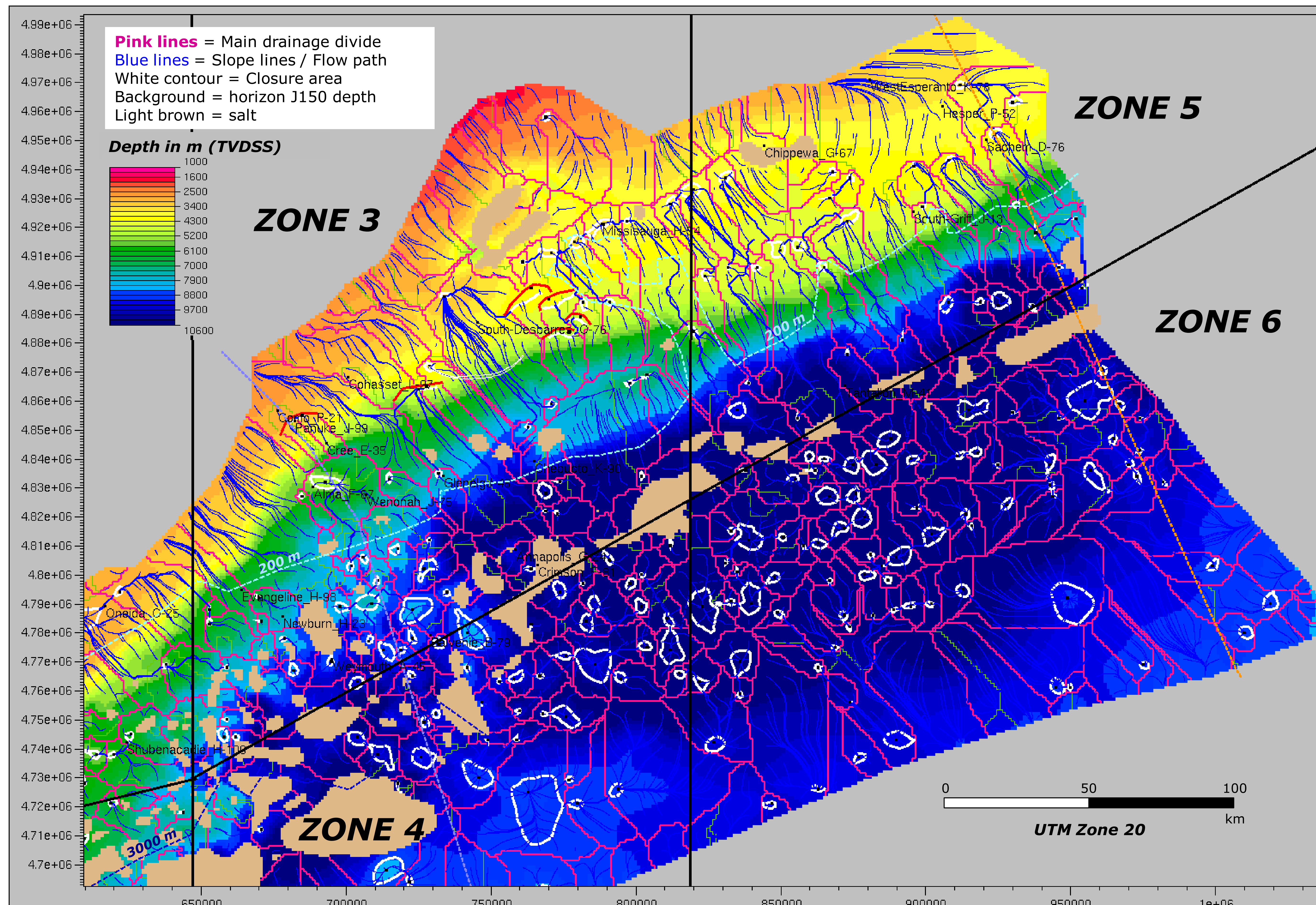




PLAY SYSTEMS
Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J163-J150)
Early-Middle-Jurassic (J200-J163)

Due to the complex shape of drainage areas in salt mini-basins (southern Zone 3, Zone 4), long-distance lateral migration is unlikely south of a line Evangeline-Annapolis.
Potential migration pathways are longer in the upper slope and on the platform (zones 3 and 5). Very long horizontal migration pathways are also possible in the deep basin (southern zones 4 and 6)

Oxfordian-Tithonian – NE



Modeling Results Confidence

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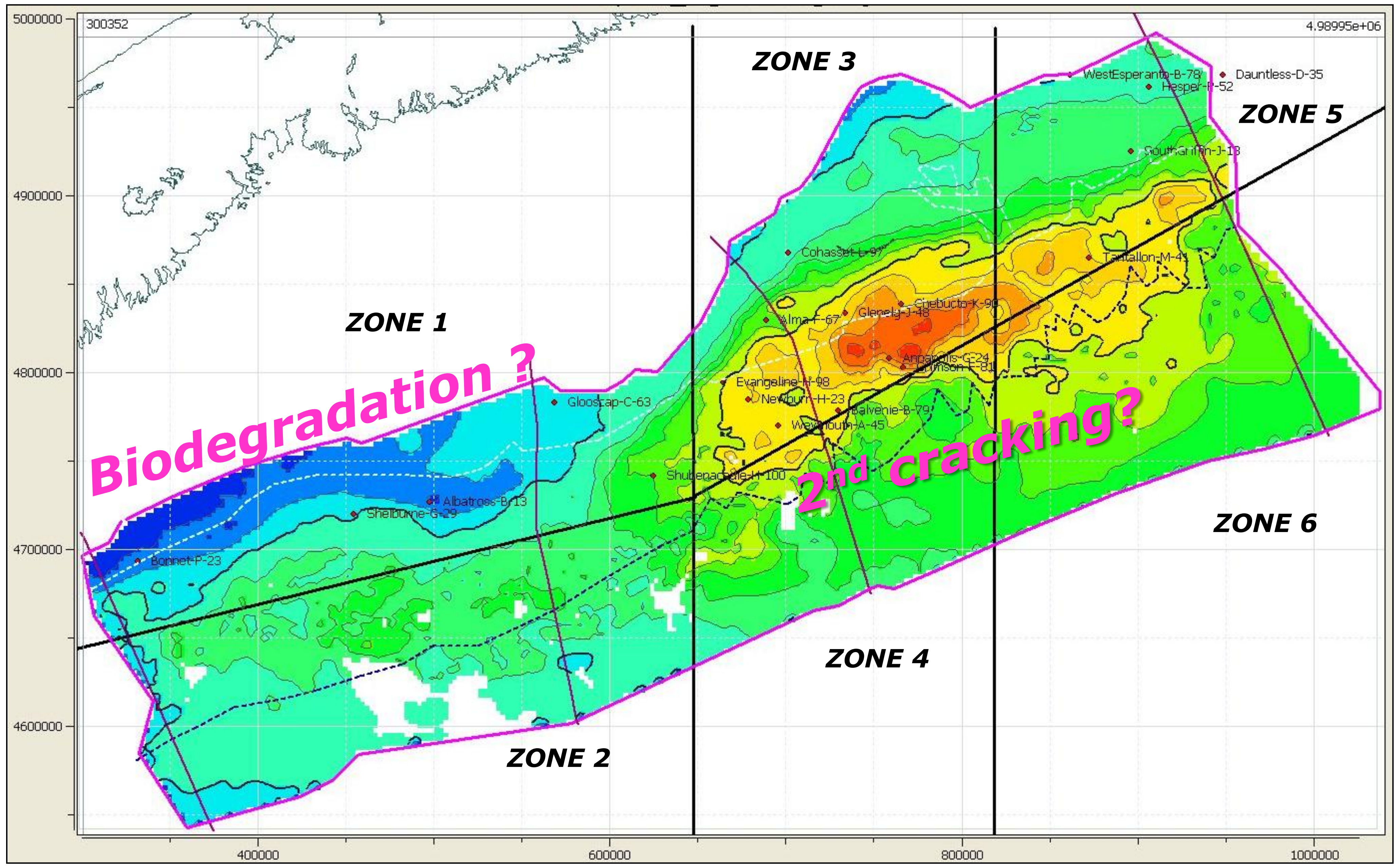
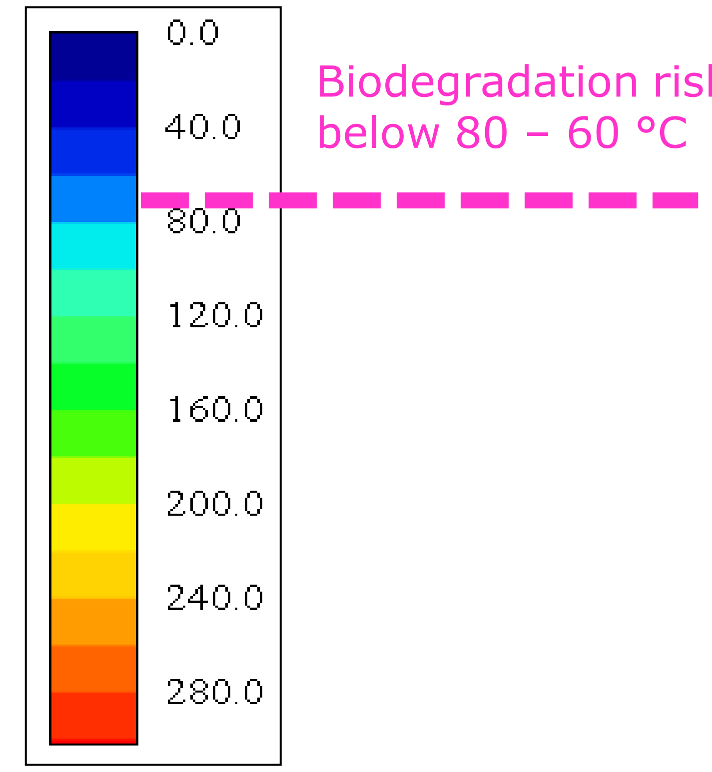




°C
Temperature at J150

TEMPERATURE / BIODEGRADATION / SECONDARY CRACKING

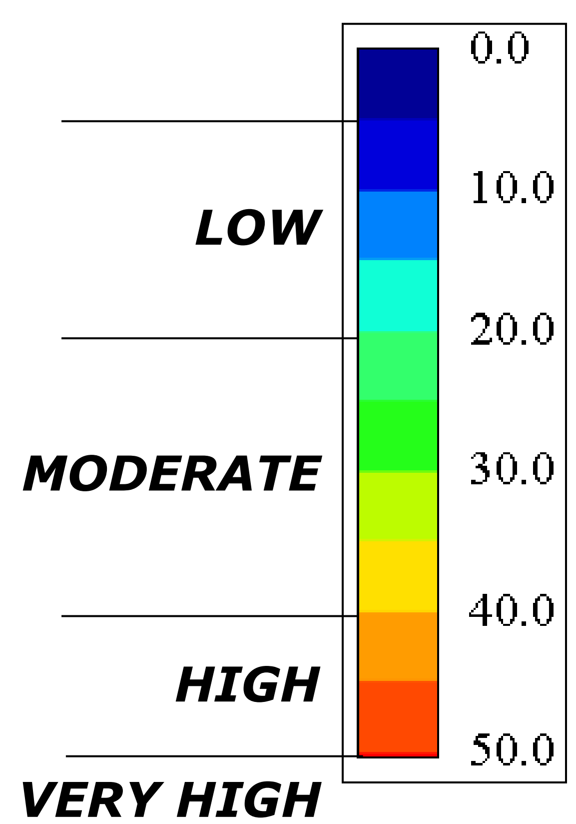
Temperature reaches a maximum of 280°C in the slope along the shelf break (Zone 3). The average temperature in the slope along the shelf break in zones 3 and 5 is around 220°C. Temperature is lower in the slope along the shelf break between zones 1 and 2 (up to 140°C).

A very limited risk of biodegradation exists on the platform, only in zone 1 (minimum temperature around 50°C). There is no risk in the basin part.

Possibility of secondary cracking exists nearly everywhere in zones 3, 4, 5, and 6 (cracking of heavy components), and particularly in deepest parts of Zone 3 (cracking of lighter components).

Oxfordian-Tithonian
Play System

MPa
Overpressure at J150

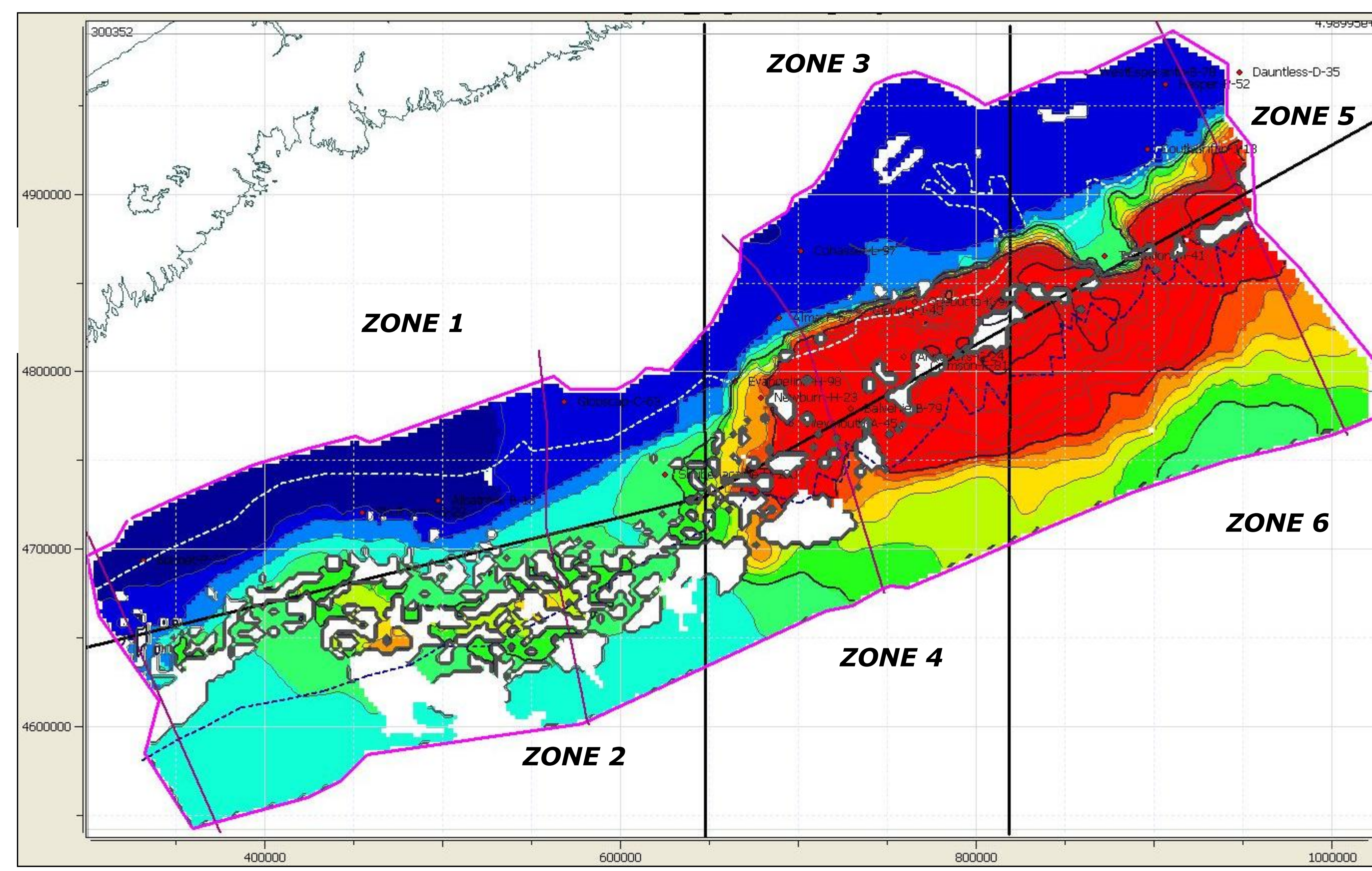


PRESSURE / OVERPRESSURE

Overpressure is very high in the slope along the shelf break, between zones 3 and 4 and between zones 5 and 6. The overpressure field in those areas is higher than 50 MPa (up to 80 MPa). Between zones 1 and 2 overpressure reaches lower values along the shelf break, around 25 MPa .

There is no overpressure or low overpressure on the platform, except along the shelf break (high overpressure).

Overpressure field in the deep basin is low to moderate in Zone 2 with a average value around 18 MPa. In the deep basin of zones 4 and 6, overpressure field is high close to the slope, and moderate seaward (around 30 MPa).



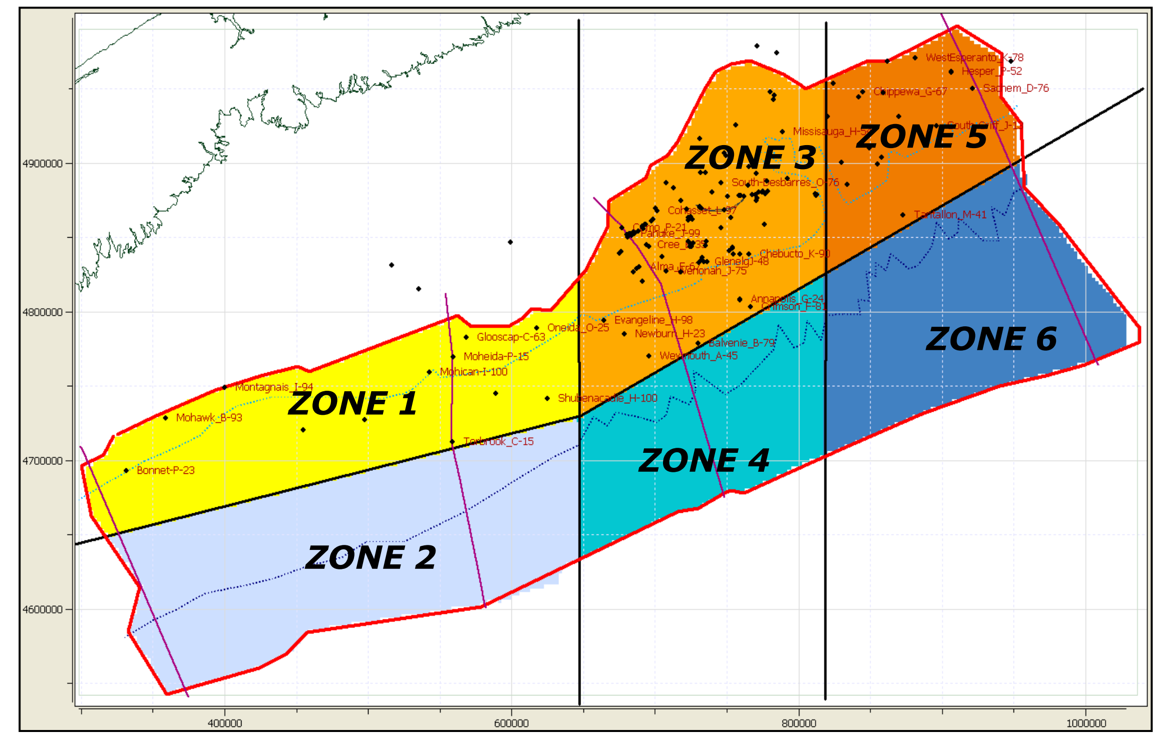
 Play System Modeling – Oxfordian-Tithonian Sequence (J163-J150) – Temperature and Overpressure

Oxfordian-Tithonian Play System

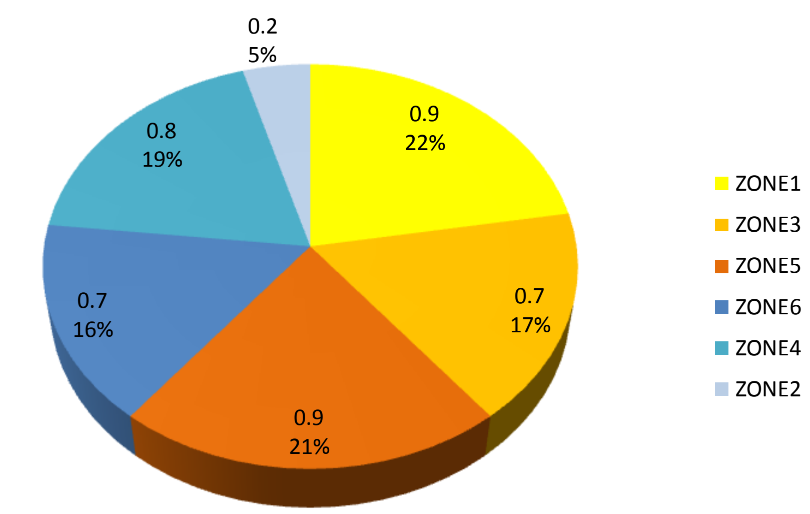
*Modeling Results Confidence**

1
2
3
4
5

*Except for following results which are only qualitative (4-5): API gravities and phase behavior.

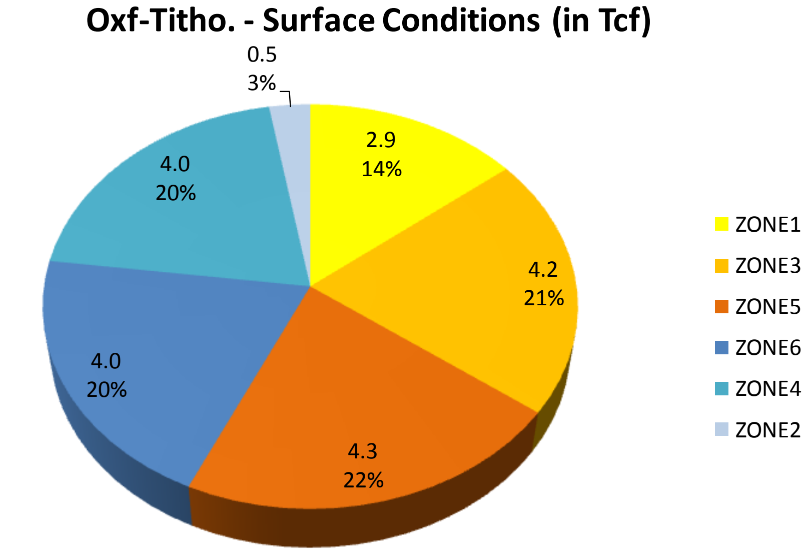


Volume of OIL EQUIVALENT in Place - by Zone
Oxf-Titho. - Surface Conditions (in Billion bble)



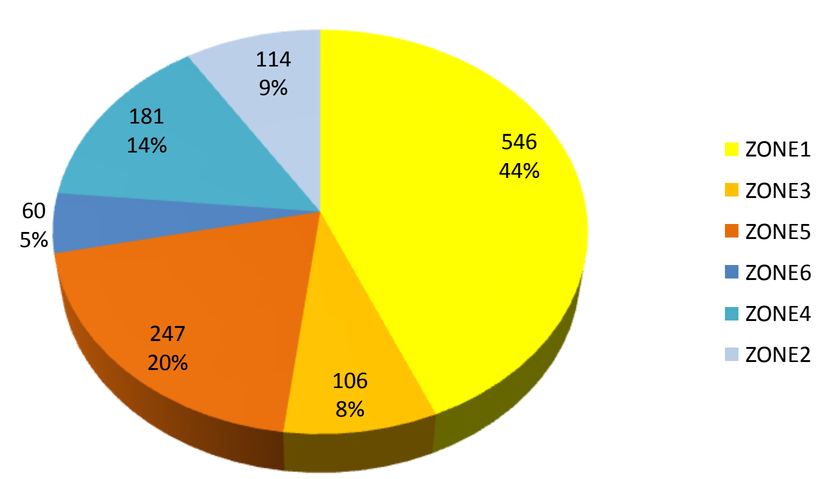
OIL EQUIVALENT In Place = 4.2 Billion bble

Volume of GAS in Place - by Zone
Oxf-Titho. - Surface Conditions (in Tcf)



GAS In Place = 20 Tcf

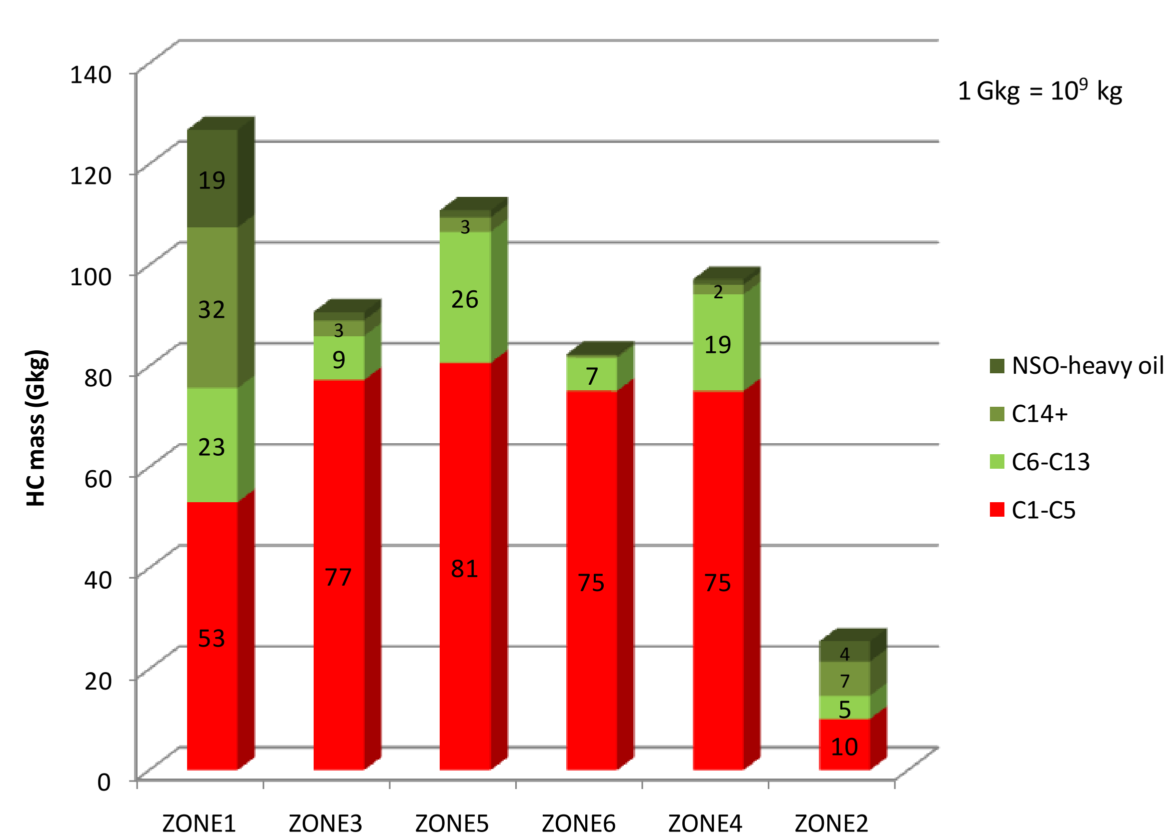
Volume of OIL in Place - by Zone
Oxf-Titho. - Surface Conditions (in Mbbl)



OIL In Place = 1.3 Billion bbl

HC Repartition
(masses and volumes – by Zone)

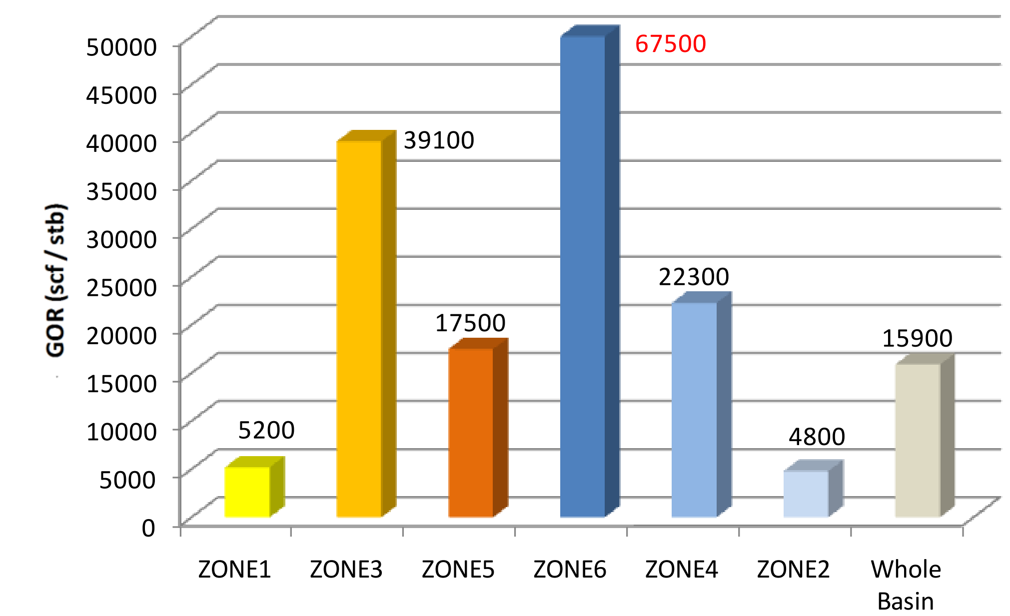
HC type by zones (mass in Gkg) - Oxf-Titho.



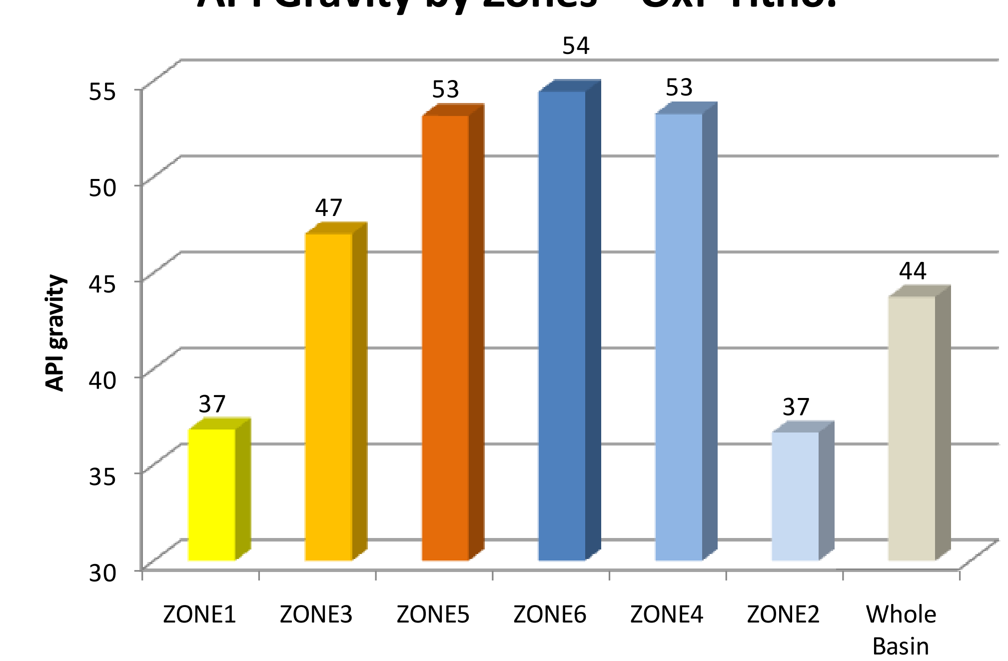
By ZONE Oxf-Titho.	TOTAL GAS Mass (Gkg) In Place - Unrisked	TOTAL OIL mass (Gkg) In Place - Unrisked	TOTAL HC mass (Gkg) In Place - Unrisked	TOTAL GAS volume in surface (Tcf) In Place - Unrisked	TOTAL OIL volume in surface (Mbbl) In Place - Unrisked	TOTAL OIL EQUIVALENT volume in surface (Million bble) In Place - Unrisked
ZONE1	53	74	127	2.9	550	900
ZONE3	77	13	91	4.2	110	700
ZONE5	81	30	111	4.3	250	900
ZONE6	75	7	82	4.0	60	700
ZONE4	75	22	97	4.0	180	800
ZONE2	10	15	26	0.5	110	200
Whole Basin	371	162	534	20	1260	4200

HC Characteristics
(Composition / Phase / Origin)

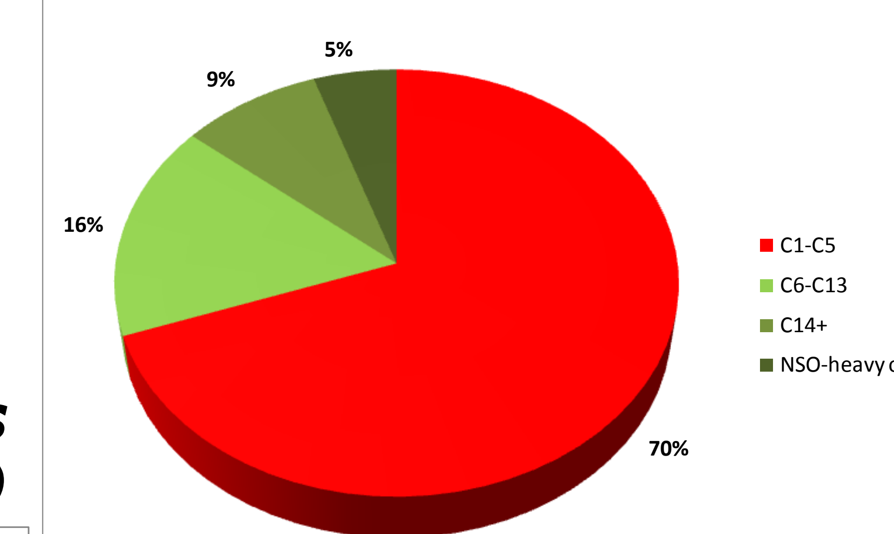
GOR by Zones (scf /stb) - Oxf-Titho.



API Gravity by Zones - Oxf-Titho.

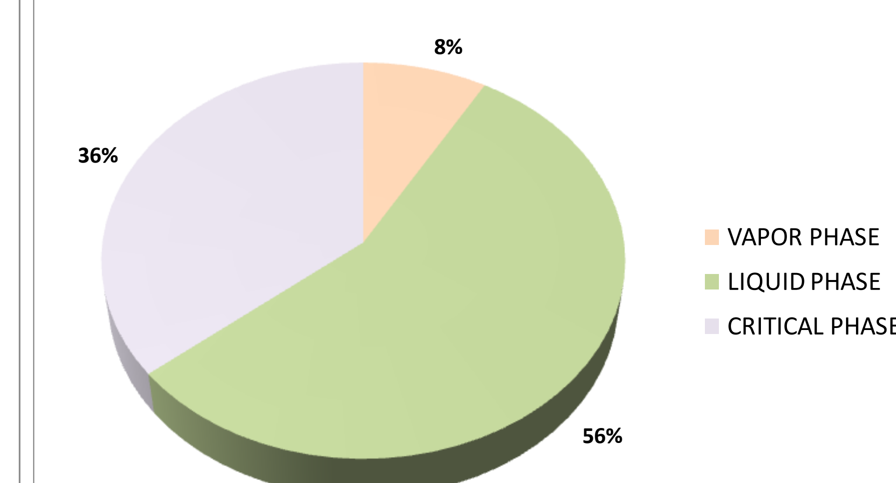


Whole Basin - Oxf-Titho. (% mass)



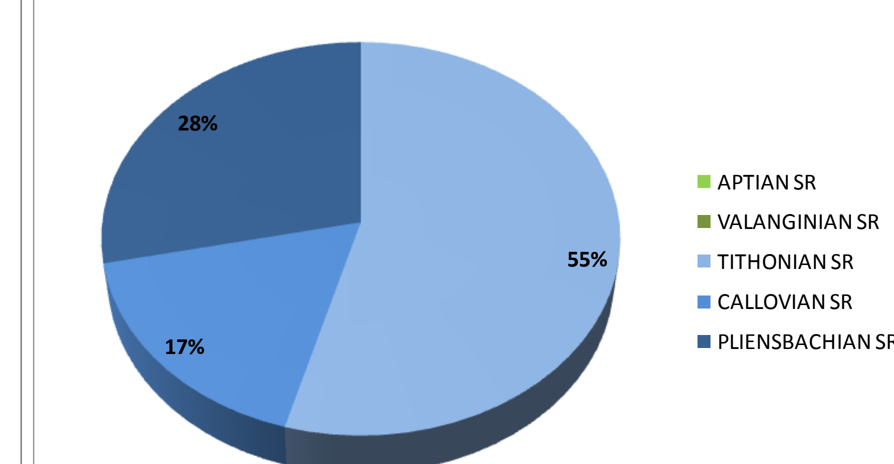
HC Composition
Chemical Fractions

Whole Basin - Oxf-Titho.
(% volume in place)



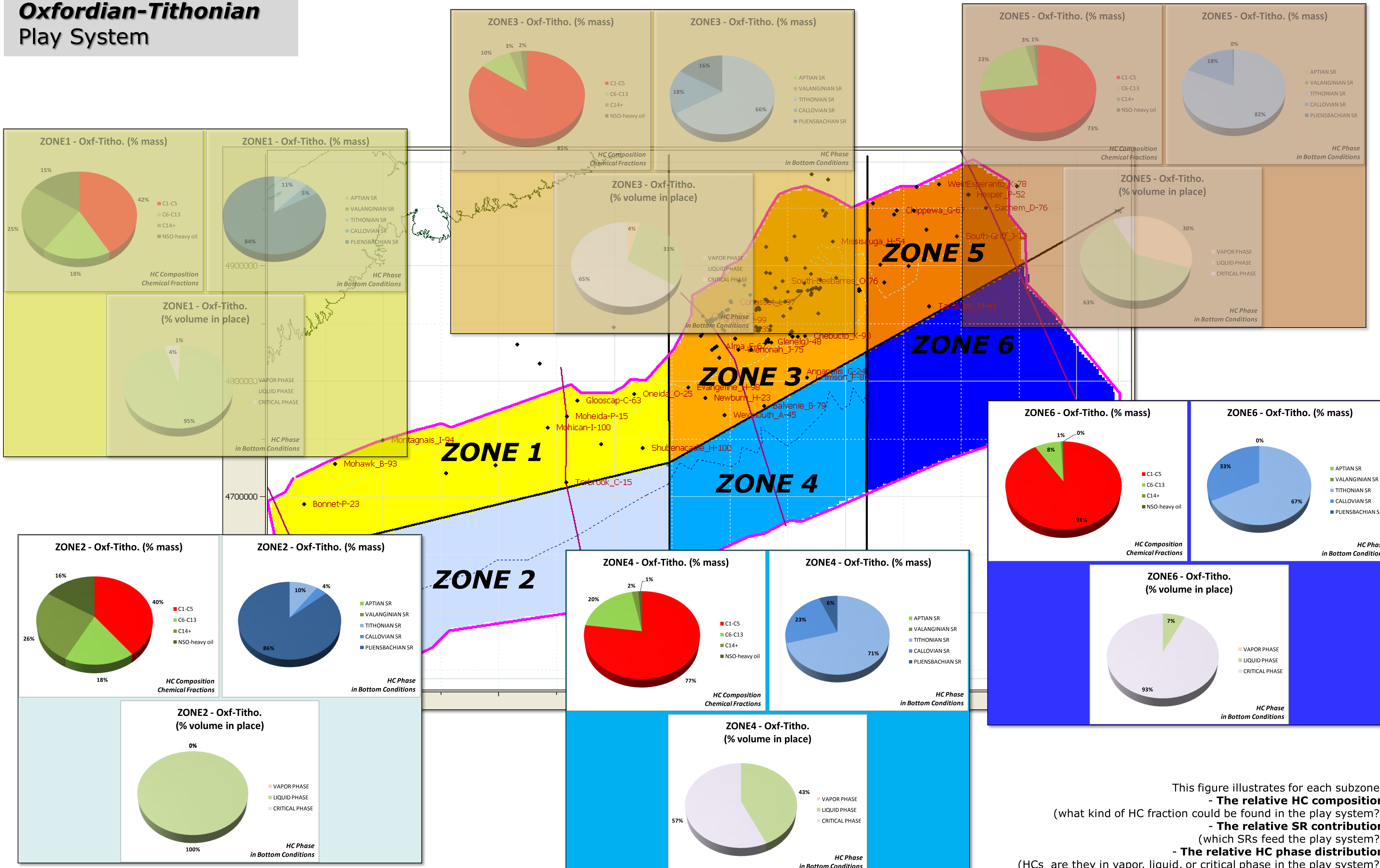
HC Phase
in Bottom Conditions

Whole Basin - Oxf-Titho. (% mass)

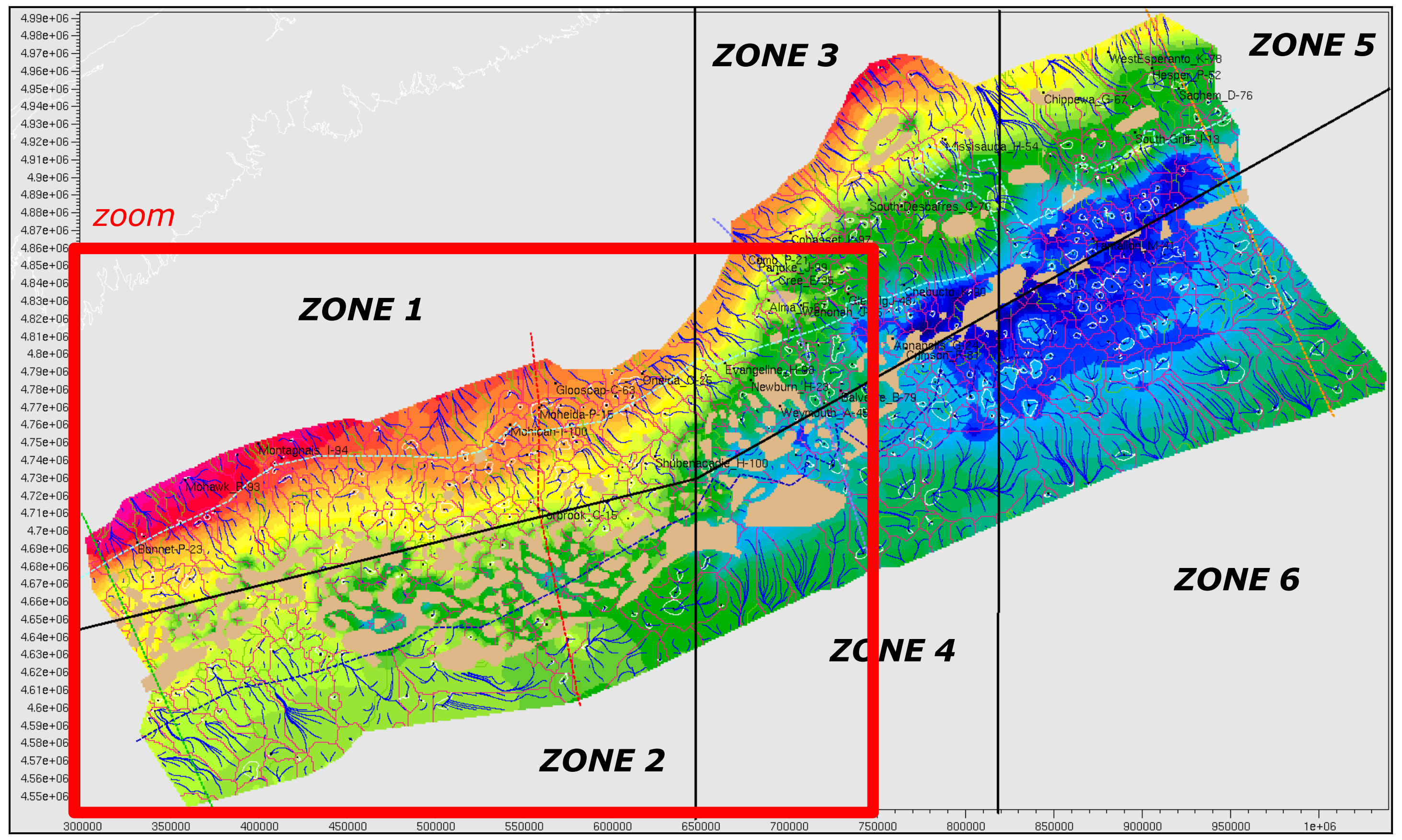


SR Contribution

Oxfordian-Tithonian Play System



This figure illustrates for each subzone:
- **The relative HC composition** (what kind of HC fraction could be found in the play system?)
- **The relative SR contribution** (which SRs feed the play system?)
- **The relative HC phase distribution** (HCs are they in vapor, liquid, or critical phase in the play system?)



PLAY SYSTEMS
Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J163-J150)
Early-Middle-Jurassic (J200-J163)

Zone	Zone Total Surface (km^2)	Number of Traps (trap surface > 2 km^2)	Number of Traps per 1000 km^2	Total Closed Areas **in km^2** (sum of traps surface if surface > 2 km^2)	% Closed Areas (/ zone total surface)	Average Drainage Area Surface **in km^2**	Total Closed Porous Volume **in Mm^3** (sum of traps volume)	Total Closed Porous Volume **in Billion bbl** (sum of traps volume)
Whole Basin	**141963**	**385**	**2.7**	**4880**	**3%**	**220**	**3700**	**23**
ZONE 1	26806	82	3.1	820	3%	230	800	5
ZONE 2	33263	63	1.9	540	2%	280	200	1
ZONE 3	24769	72	2.9	730	3%	190	700	4
ZONE 4	18250	41	2.2	720	4%	250	200	1
ZONE 5	14694	48	3.3	640	4%	170	1200	8
ZONE 6	24181	79	3.3	1420	6%	210	500	3

CLOSED AREAS / CLOSED POROUS VOLUMES / DRAINAGE AREAS

The **closed area** (or closure area) is defined by structural maps. It corresponds to the extend of a structural trap (4 way closure). About 2% of the study area is a closed area. Closed areas evolves during the geological history due to structural evolutions.

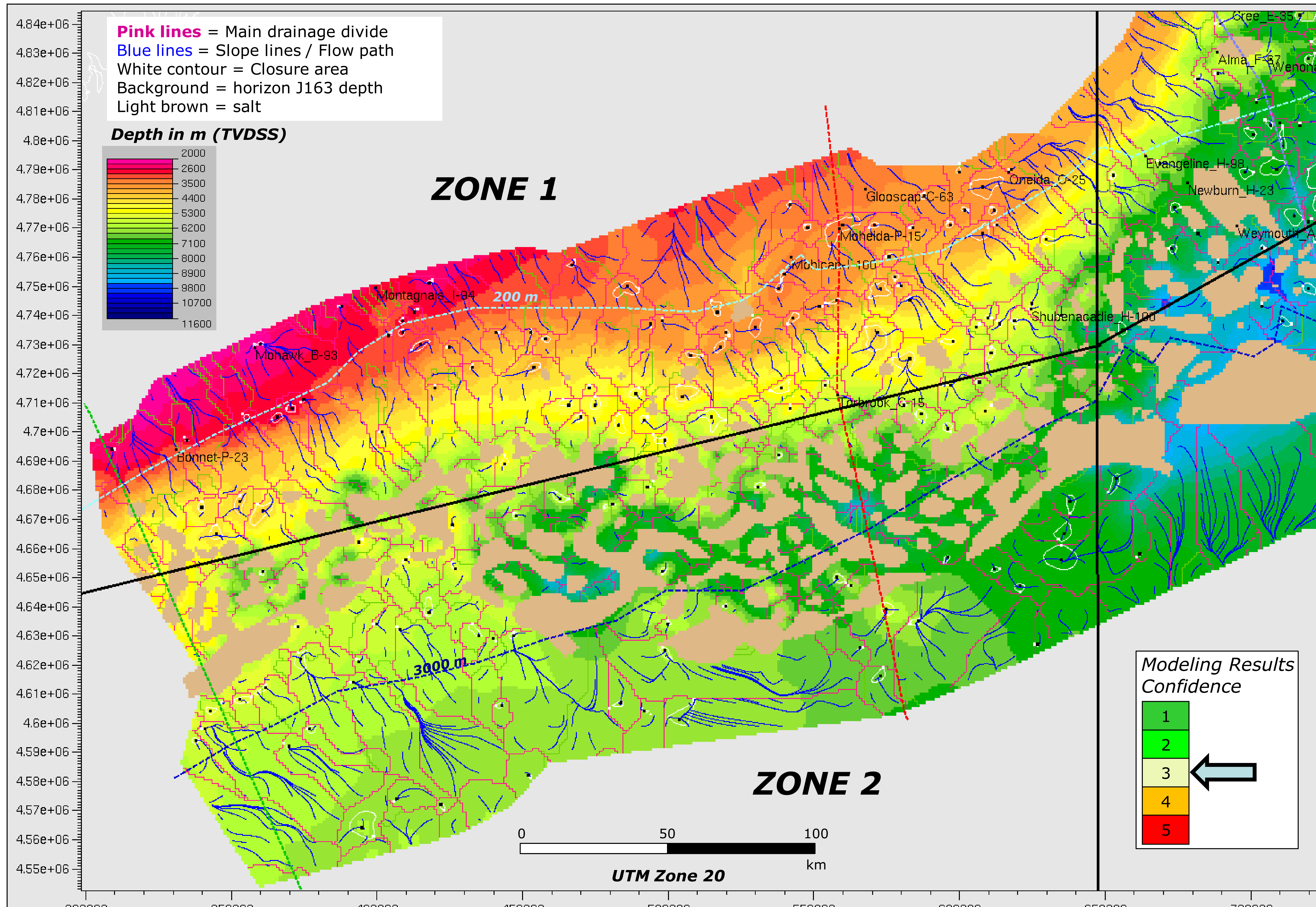
The **closed porous volume** is the volume of voids in a structural trap. This volume can be filled with water or hydrocarbons. It usually decreases during the geological history due to the compaction. Porosity modeling is done by Temis®.

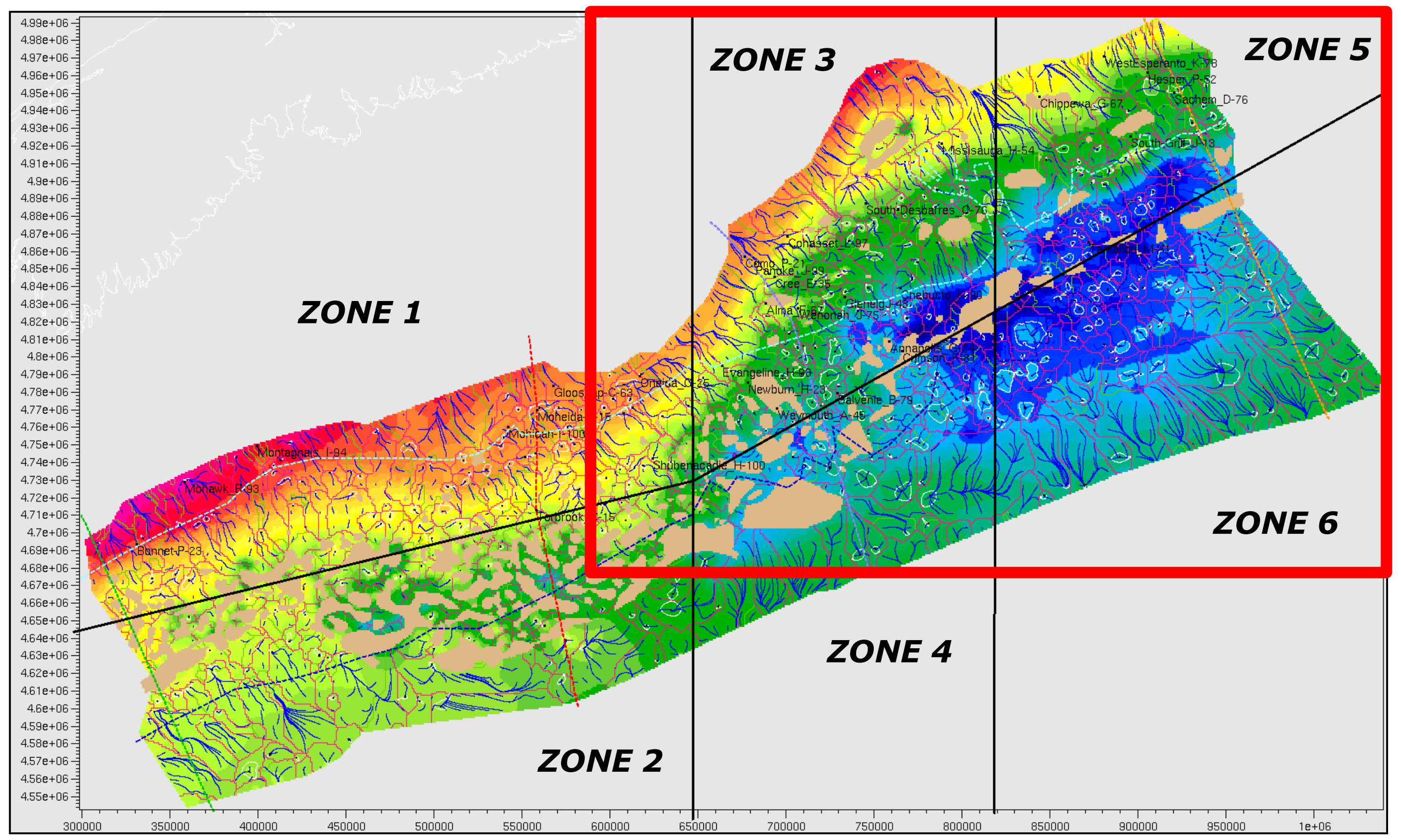
Each trap is associated to a **drainage area** defined by slope lines, impermeable lithologies, permeable faults. The size of the drainage area may impact the charge of the trap.

The **Early-Middle-Jurassic play system** includes the Scatarie Formation Play, and other poorly known formations.

Due to the complex shape of drainage areas in Zone 2 (salt mini-basins), long-distance lateral migration is unlikely in that part of the basin. Moreover the existence of relatively permeable faults along active salt bodies would increase the vertical migration, and so the hydrocarbon "leakage" out of this play (presence of seeps in this area). As a consequence potential mature SR in Zone 2 can hardly feed reservoirs in Zone 1. Potential migration pathways are longer in the upper slope and on the platform (Zone 1). In Zone 1, traps seems bigger and more numerous eastward.

Early-Middle-Jurassic – SW

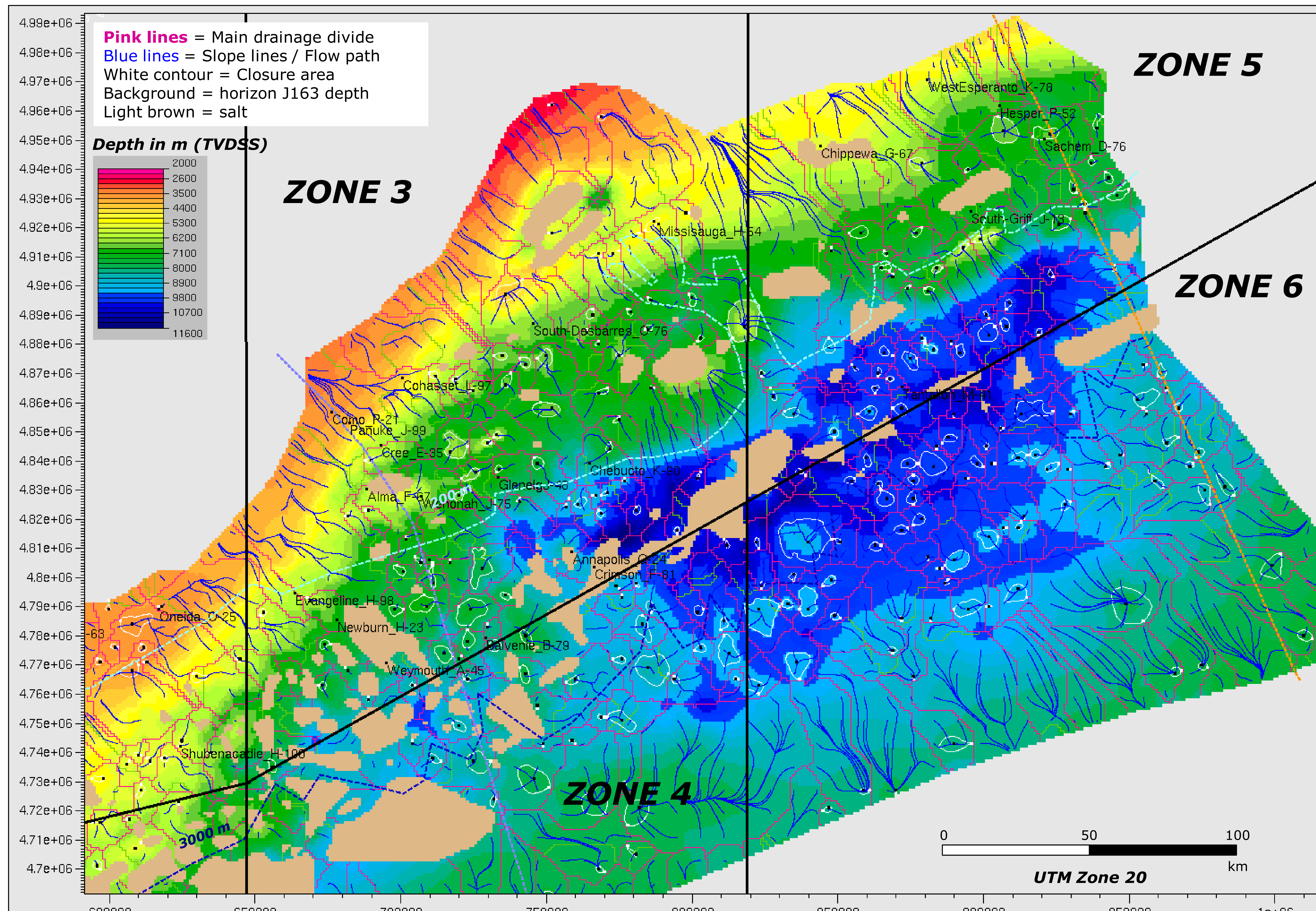




Due to the complex shape of drainage areas in salt mini-basins (southern Zone 3, Zone 4), long-distance lateral migration is unlikely south of a line Evangeline-Annapolis-Tantallon. However this does not disturb petroleum systems in the Sable Sub Basin (Zone 3) because the most mature SRs are found in the deep depression between Evangeline, Annapolis, and Glenelg (north of the line Evangeline-Annapolis). Potential migration pathways are longer in the upper slope and on the platform (zones 3 and 5).
Very long horizontal migration pathways are also possible in the deep basin (southern zones 4 and 6).

Early-Middle-Jurassic – NE

PLAY SYSTEMS
Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J163-J150)
Early-Middle-Jurassic (J200-J163)



Modeling Results Confidence
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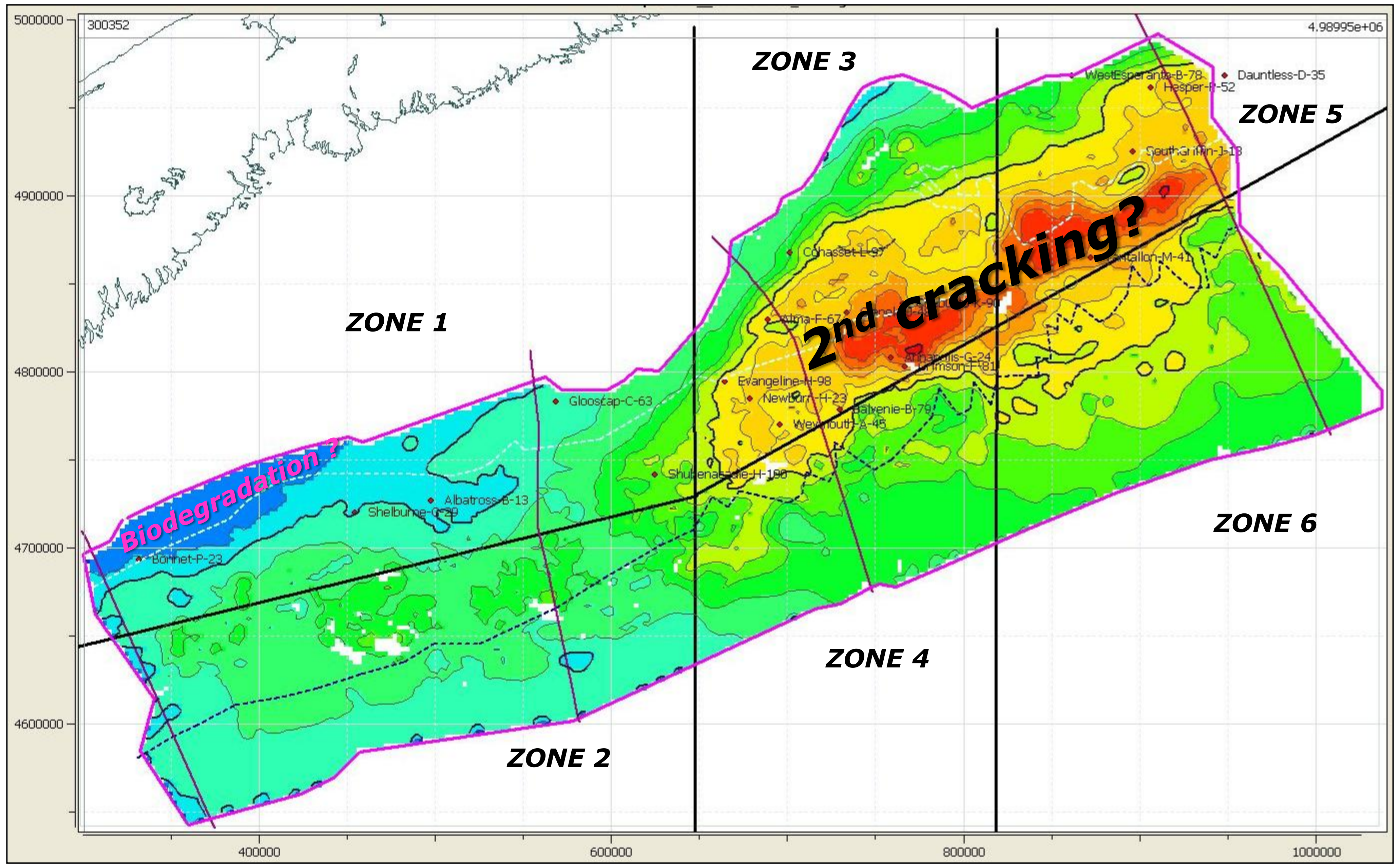
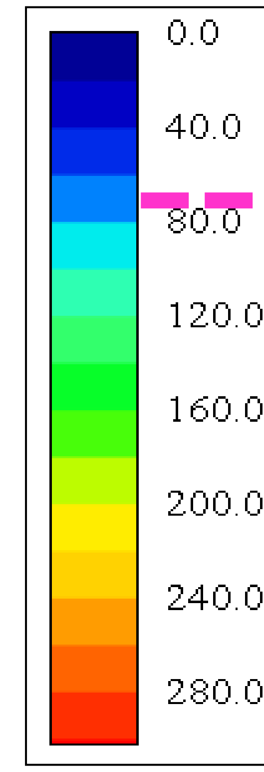




°C
Temperature at J163

TEMPERATURE / BIODEGRADATION / SECONDARY CRACKING

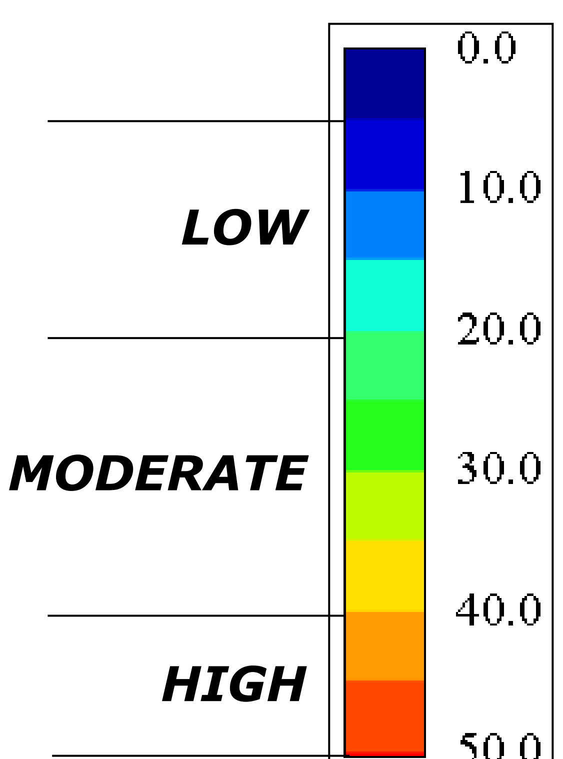
Temperature reaches a maximum of 300°C in the slope along the shelf break in zones 3 and 5 (temperature always above 200°C). Maximum temperature is lower between zones 1 and 2, it reaches 150°C in the slope along the shelf break.

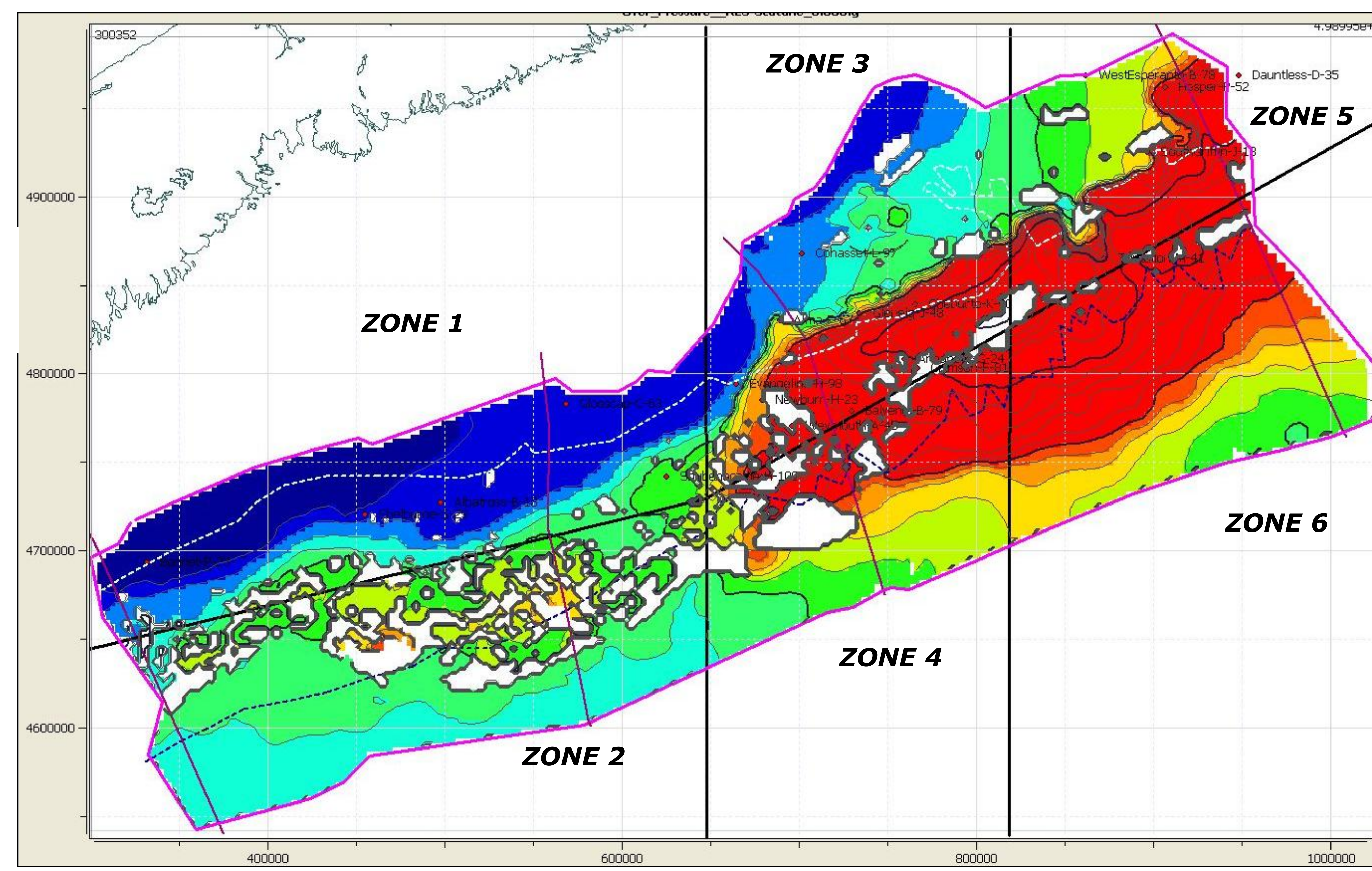
A very limited risk of biodegradation exists on the platform, only in Zone 1 (minimum temperature around 70°C).

Possibility of secondary cracking exists nearly everywhere in zones 3, 4, 5 and 6 (cracking of heavy components), particularly in zones 3 and 5 (cracking of lighter components), and locally in Zone 2 (cracking of heavy components).

Early-Middle-Jurassic Play System

MPa
Overpressure at J163





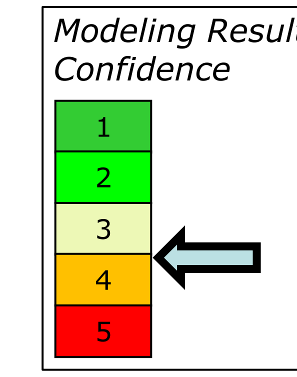
PRESSURE / OVERPRESSURE

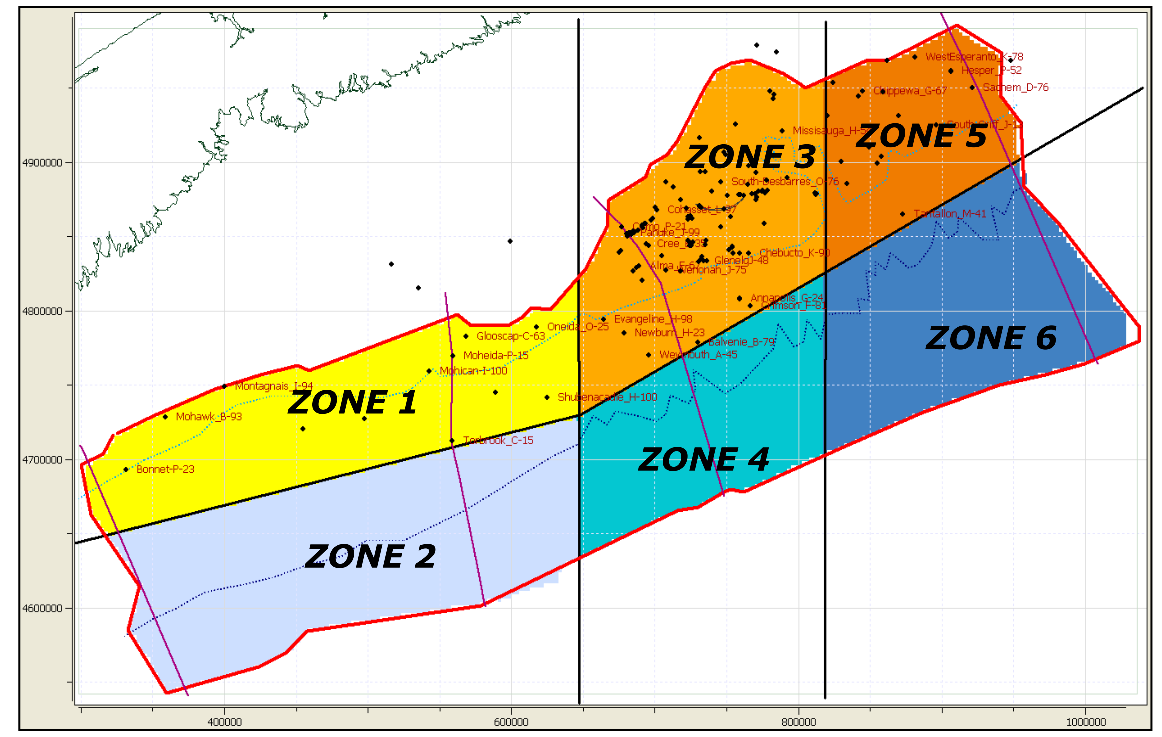
Overpressure is very high in the slope along the shelf break, between zones 3 and 4 and between zones 5 and 6. The overpressure field in those areas is higher than 50 MPa (maybe up to 100 MPa). Between zones 1 and 2 overpressure reaches moderate values along the shelf break, around 30 MPa.

There is no overpressure on the platform in Zone 1. On the platform of zones 3 and 5 overpressure increases to the East, starting from low overpressure values overpressure in the West to reach high values (more than 50 MPa) in the eastern part. High overpressure also exists along the shelf break (southward).

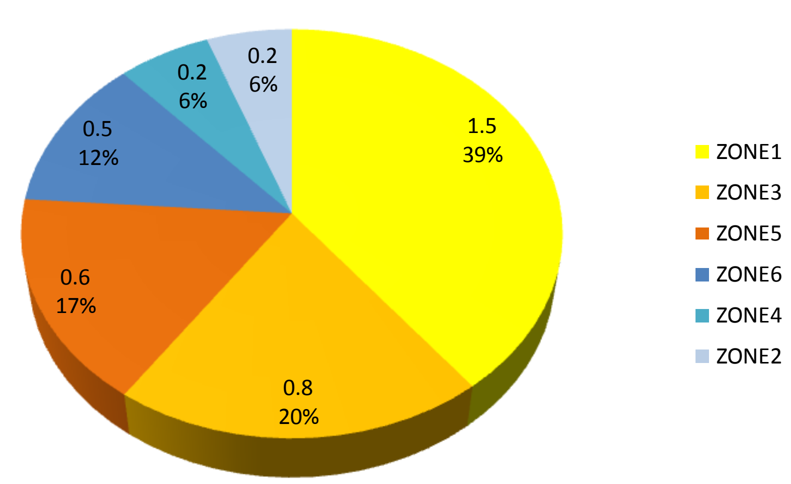
Overpressure field in the deep basin, is low to moderate in Zone 2 with a average value around 18 MPa. In the deep basin of zones 4 and 6, overpressure field is high close to the slope, and moderate seaward (around 30 MPa).

Early-Middle-Jurassic Play System



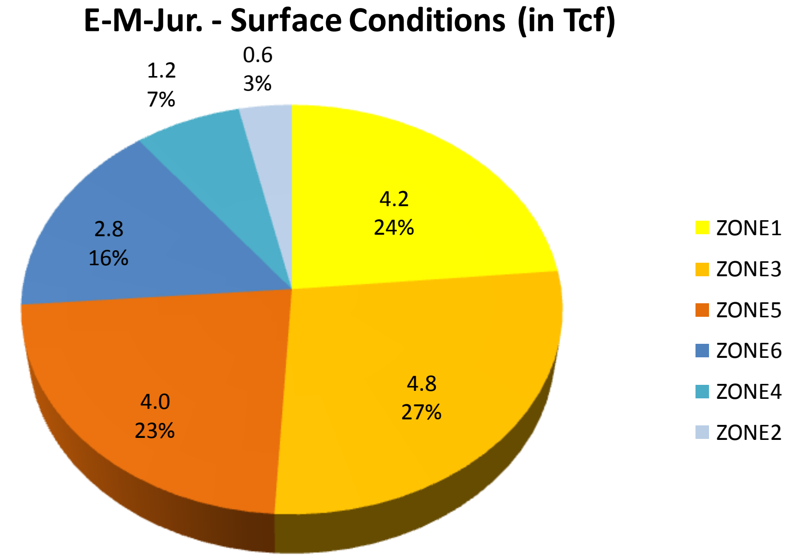


Volume of OIL EQUIVALENT in Place - by Zone
E-M-Jur. - Surface Conditions (in Billion bble)



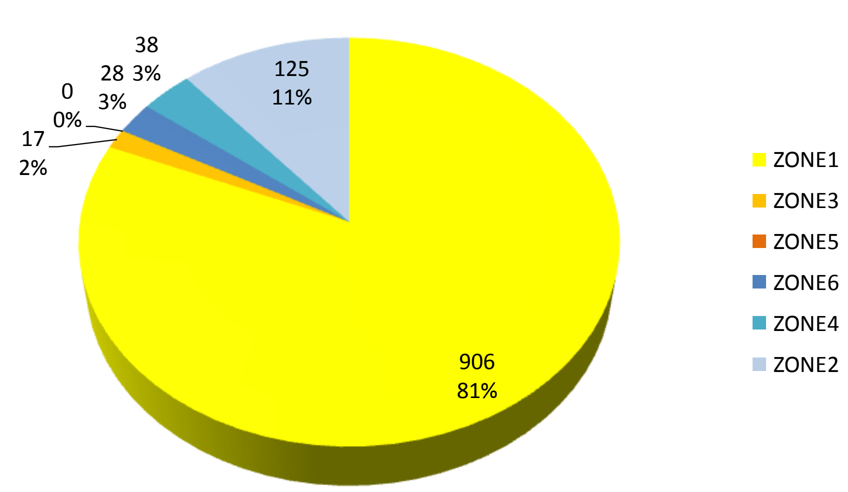
OIL EQUIVALENT In Place = 3.8 Billion bble

Volume of GAS in Place - by Zone
E-M-Jur. - Surface Conditions (in Tcf)



GAS In Place = 18 Tcf

Volume of OIL in Place - by Zone
E-M-Jur. - Surface Conditions (in Mbbl)

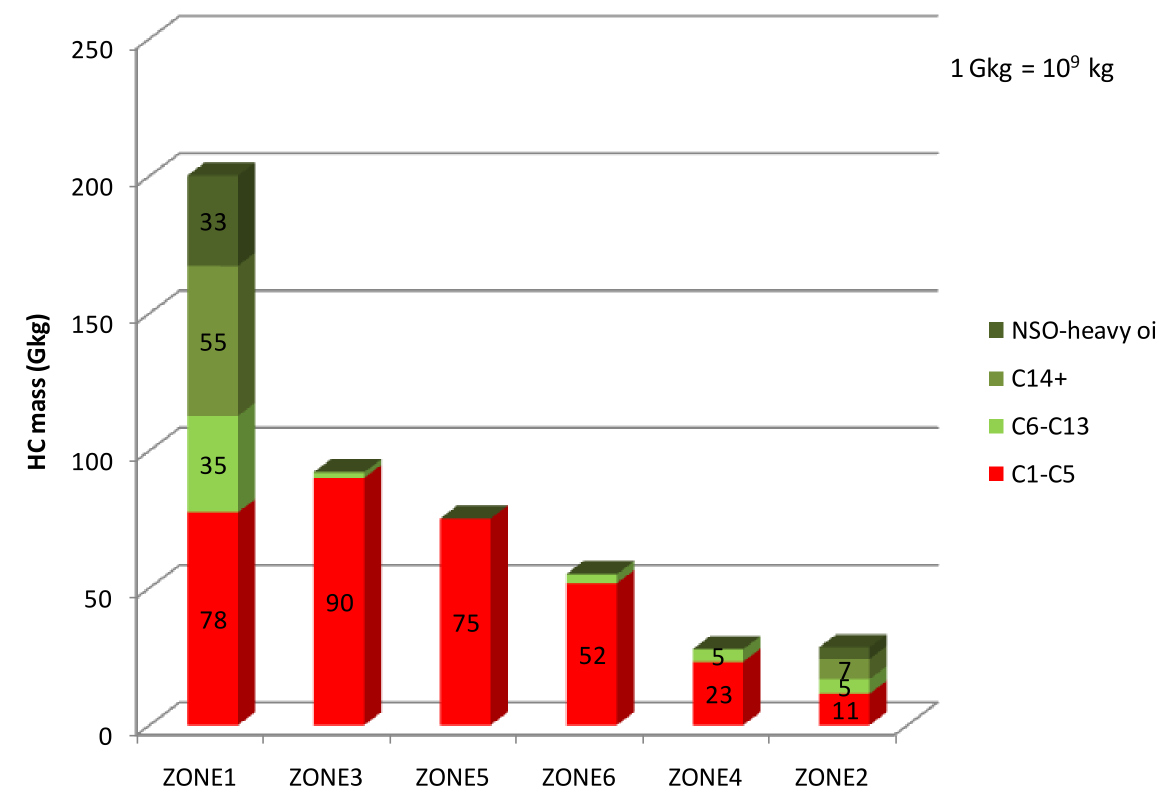


OIL In Place = 1.1 Billion bbl

HC Repartition

(masses and volumes – by Zone)

HC type by zones (mass in Gkg) - E-M-Jur.

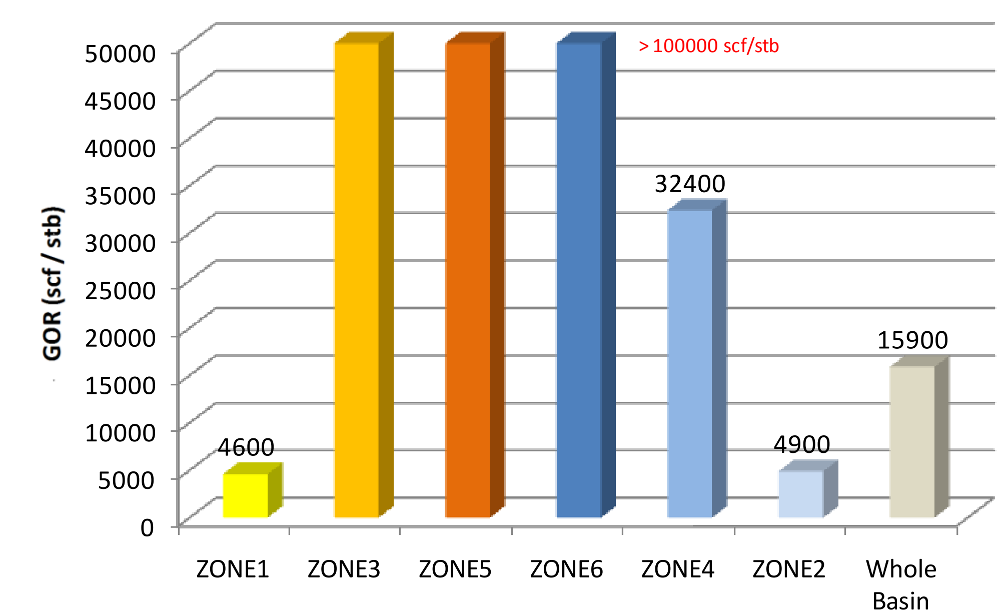


By ZONE E-M-Jur.	TOTAL GAS Mass (Gkg) In Place - Unrisked	TOTAL OIL mass (Gkg) In Place - Unrisked	TOTAL HC mass (Gkg) In Place - Unrisked	TOTAL GAS volume in surface (Tcf) In Place - Unrisked	TOTAL OIL volume in surface (Mbbl) In Place - Unrisked	TOTAL OIL EQUIVALENT volume in surface (Million bble) In Place - Unrisked
ZONE1	78	123	200	4.2	910	1500
ZONE3	90	2	92	4.8	20	800
ZONE5	75	0	75	4.0	0	600
ZONE6	52	3	55	2.8	30	500
ZONE4	23	5	28	1.2	40	200
ZONE2	11	17	28	0.6	130	200
Whole Basin	329	150	479	18	1130	3800

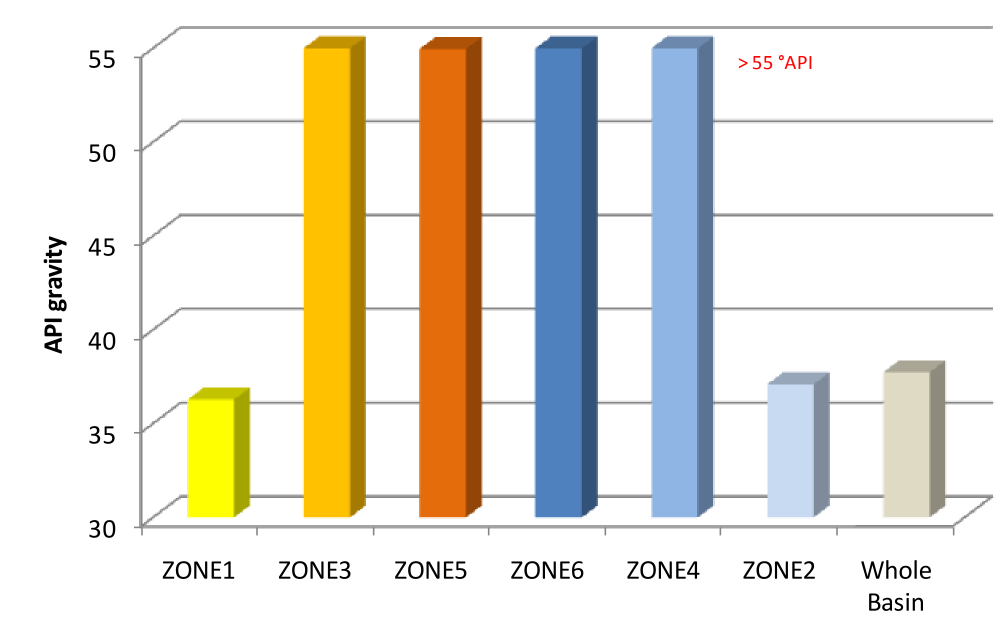
HC Characteristics

(Composition / Phase / Origin)

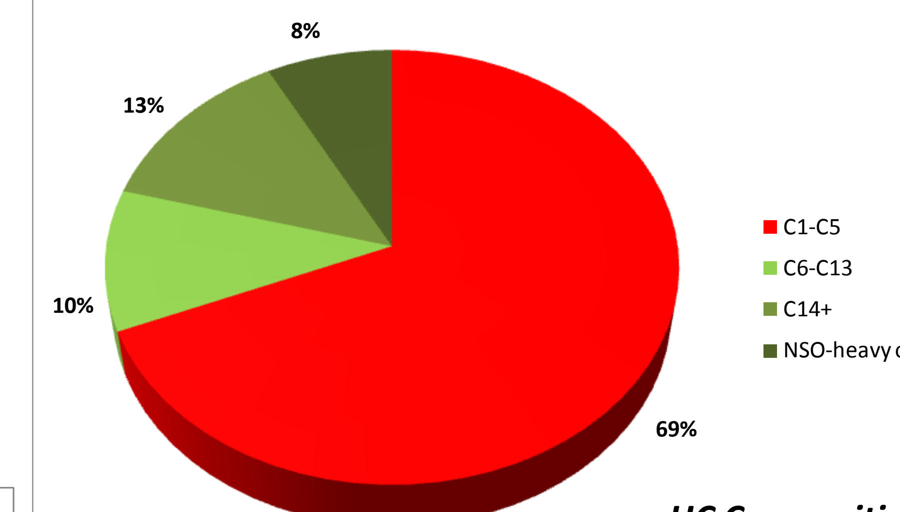
GOR by Zones (scf /stb) - E-M-Jur.



API Gravity by Zones - E-M-Jur.

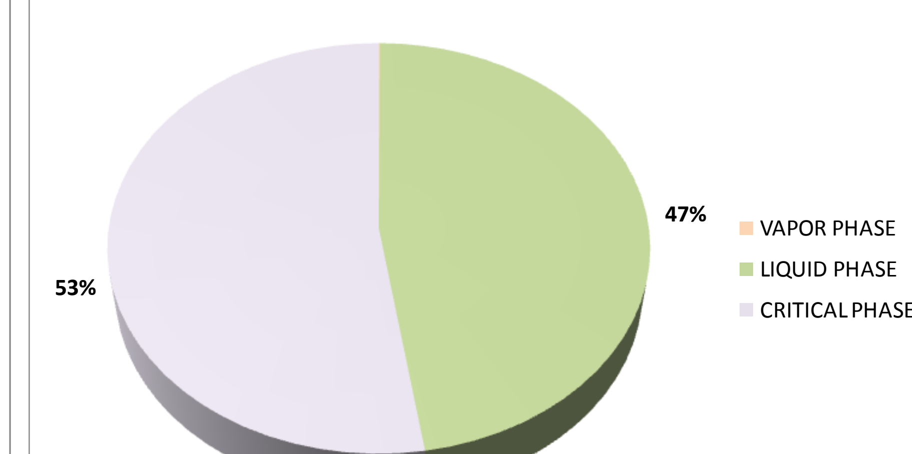


Whole Basin - E-M-Jur. (% mass)



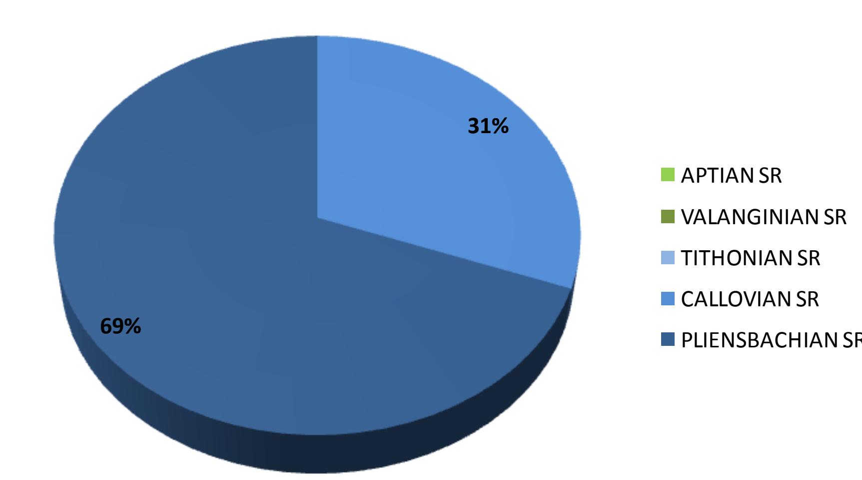
HC Composition
Chemical Fractions

Whole Basin - E-M-Jur.
(% volume in place)



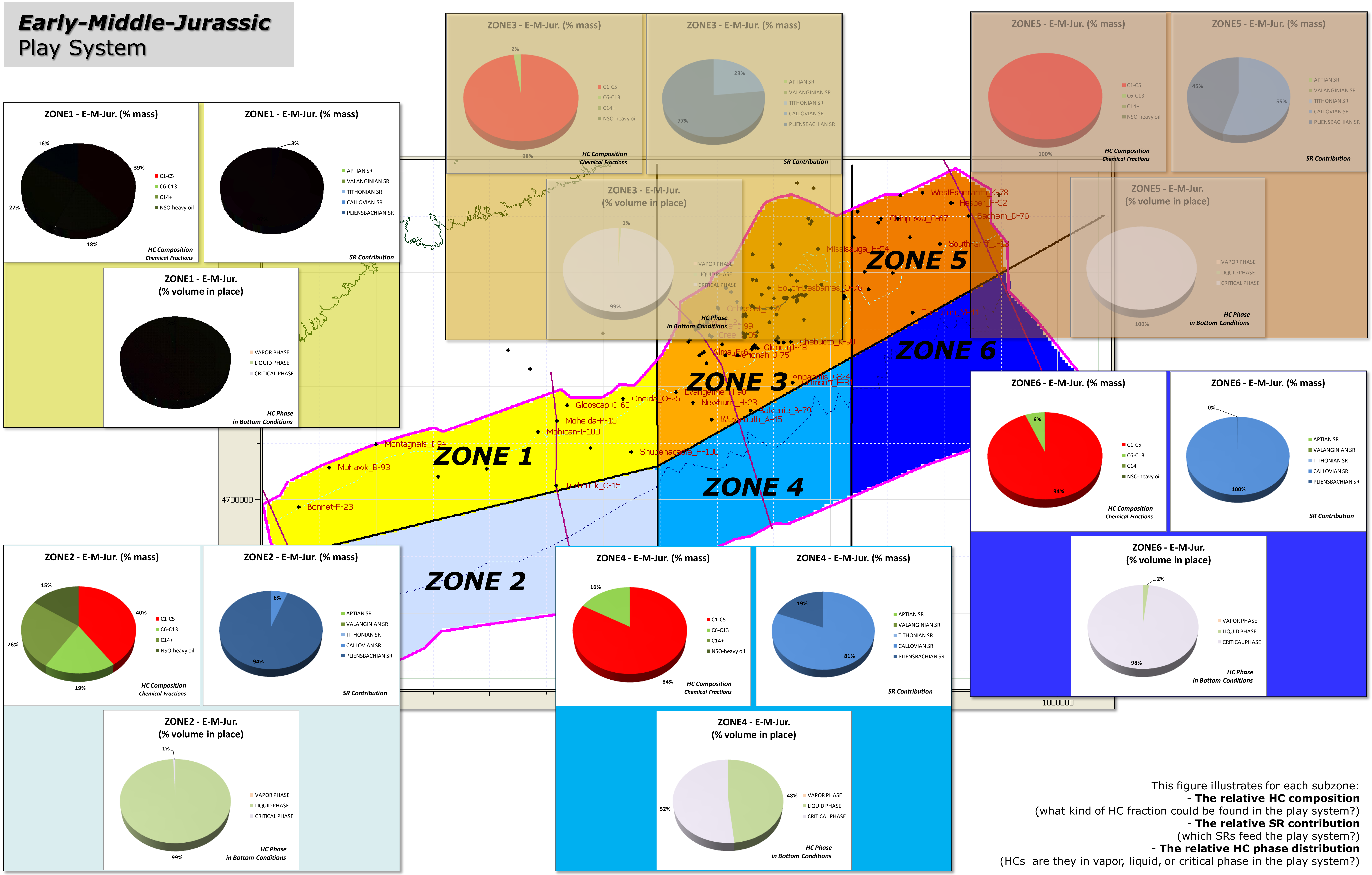
HC Phase
in Bottom Conditions

Whole Basin - E-M-Jur. (% mass)



SR Contribution

Early-Middle-Jurassic Play System



This figure illustrates for each subzone:
- **The relative HC composition**
(what kind of HC fraction could be found in the play system?)
- **The relative SR contribution**
(which SRs feed the play system?)
- **The relative HC phase distribution**
(HCs are they in vapor, liquid, or critical phase in the play system?)

Play System Modeling – Early-Middle-Jurassic Sequence (J200-J163) – Hydrocarbon Characteristics (by Zone)

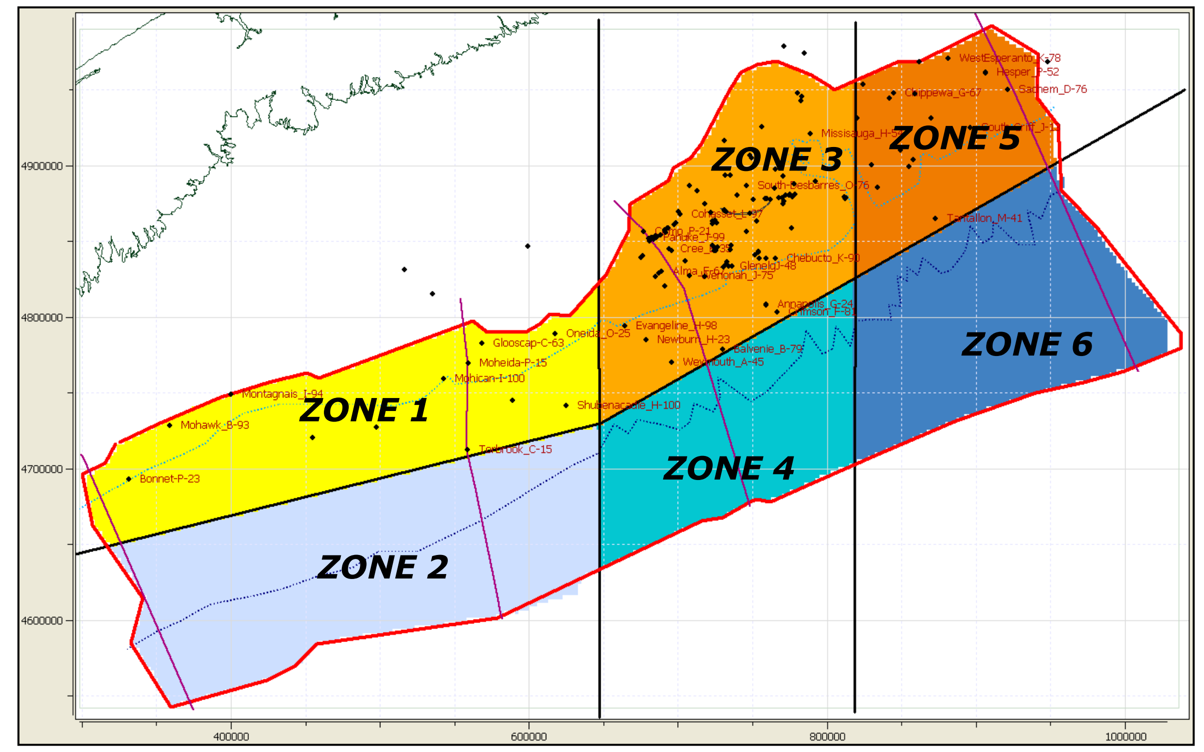
CHAPTER 7-3

BASIN MODELING – TEMIS 3D

7-3-4

3D Modeling
SYNTHESIS and CONCLUSION

PLAY SYSTEMS
Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J163-J150)
Early-Middle-Jurassic (J200-J163)



*Modeling Results Confidence**

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4
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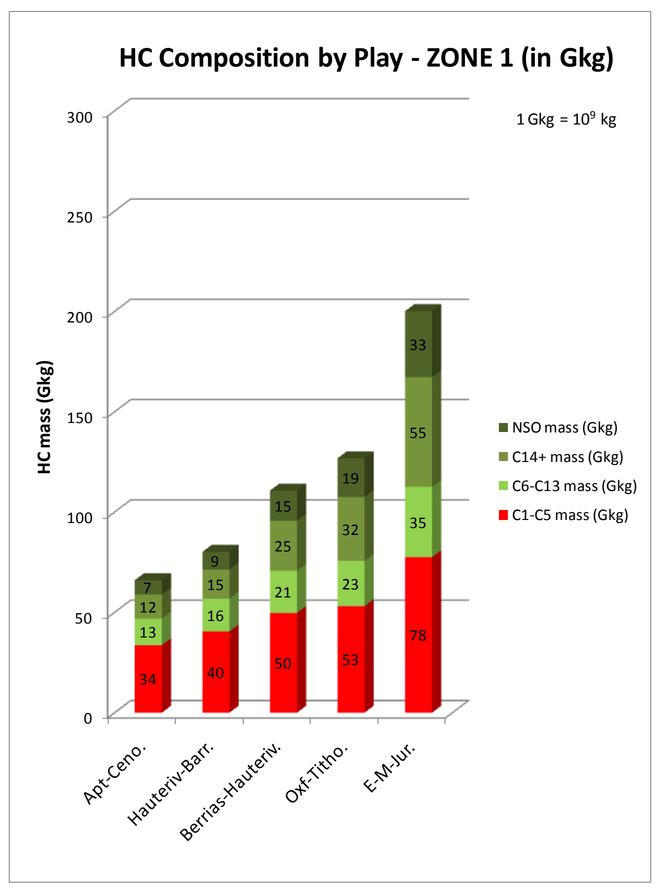
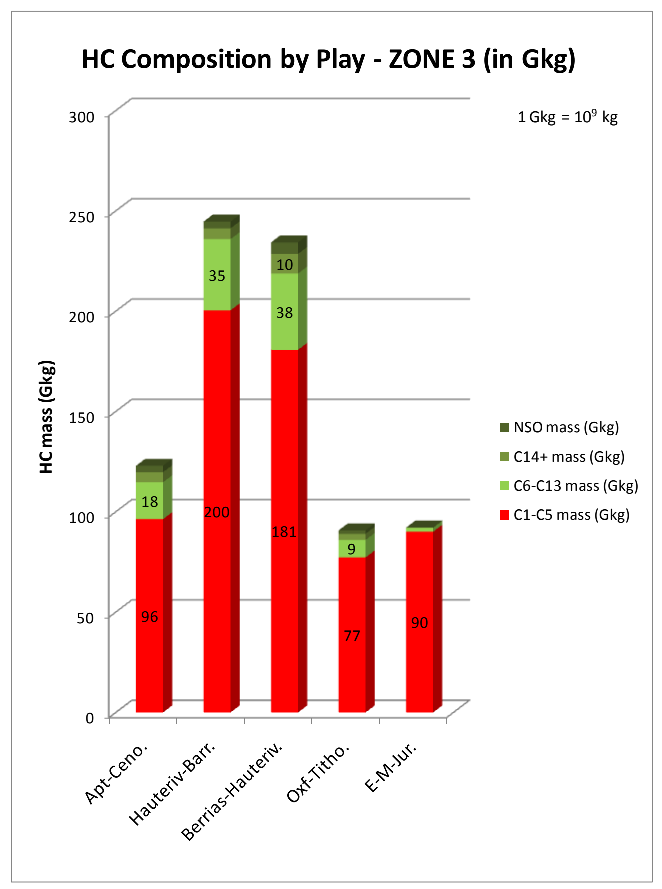
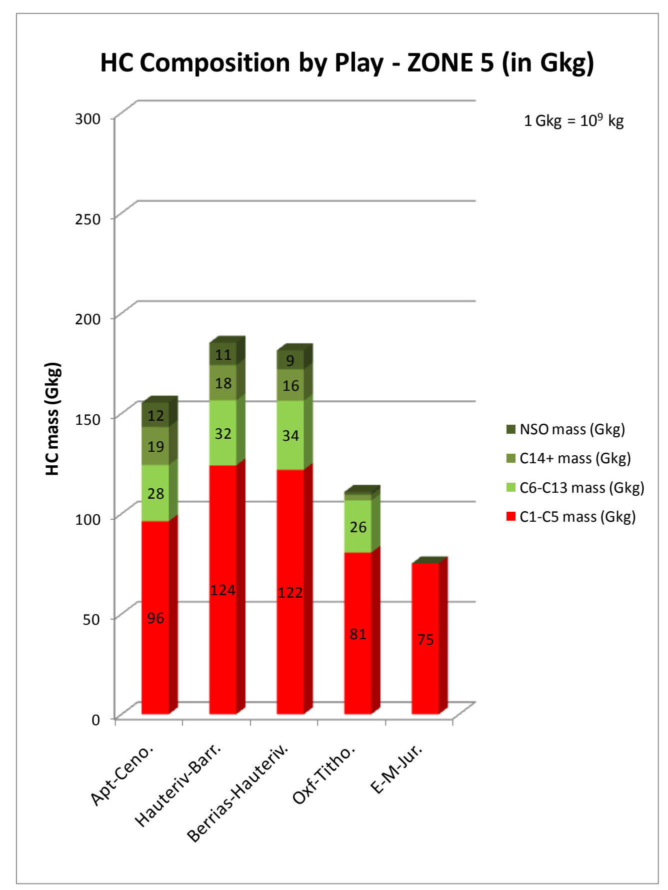
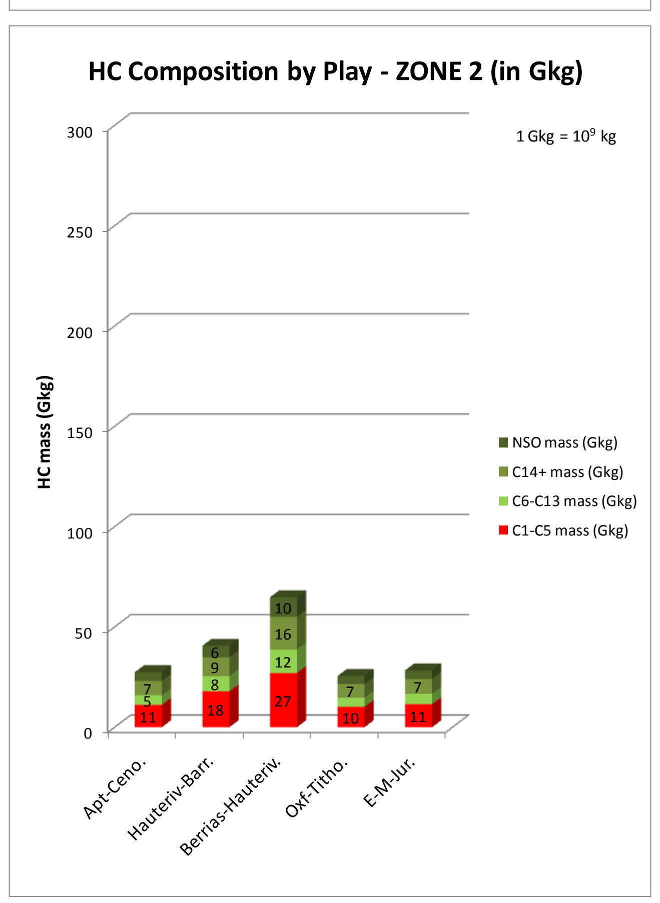
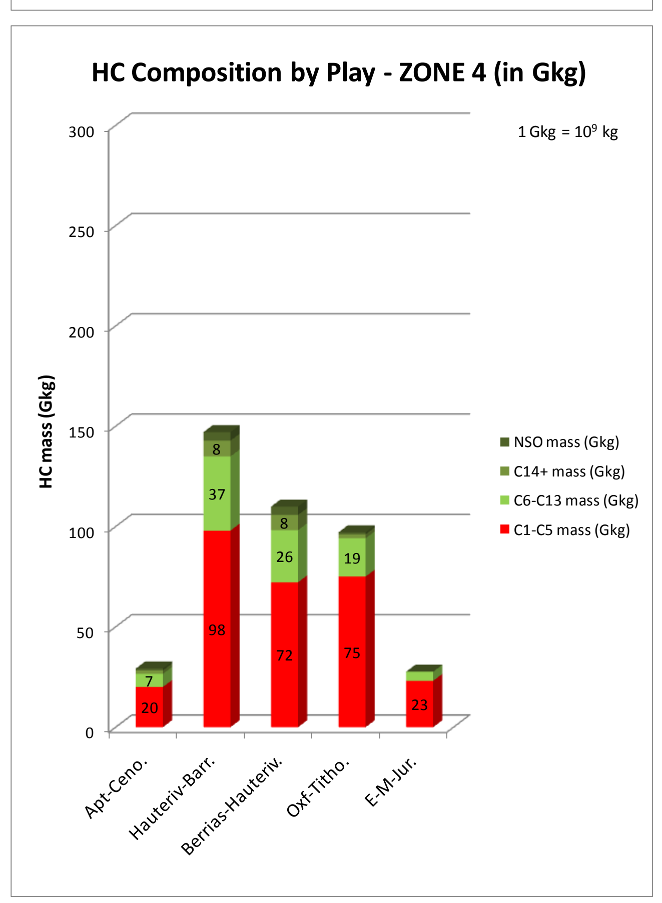
ABSOLUTE HC masses

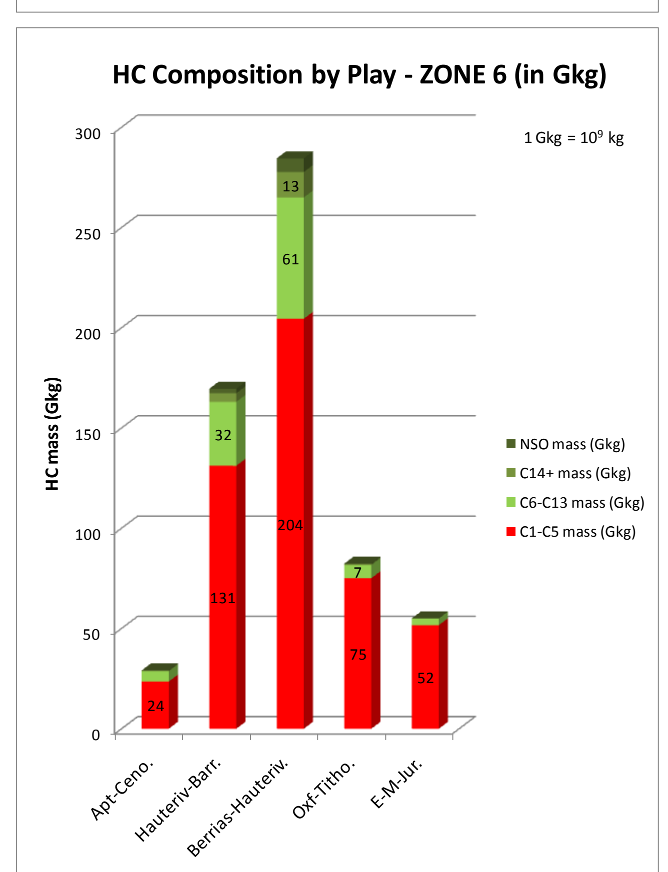




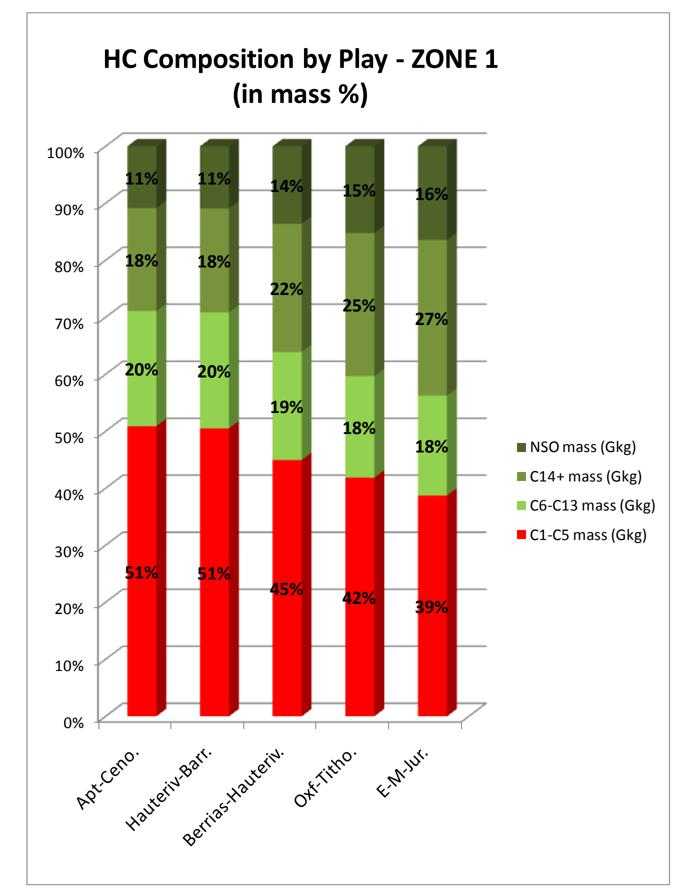


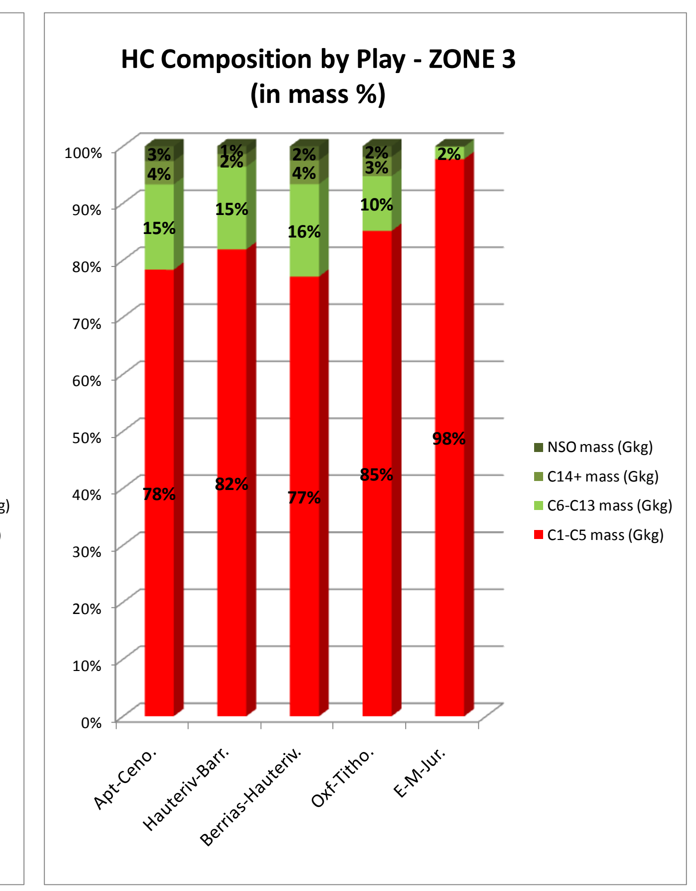


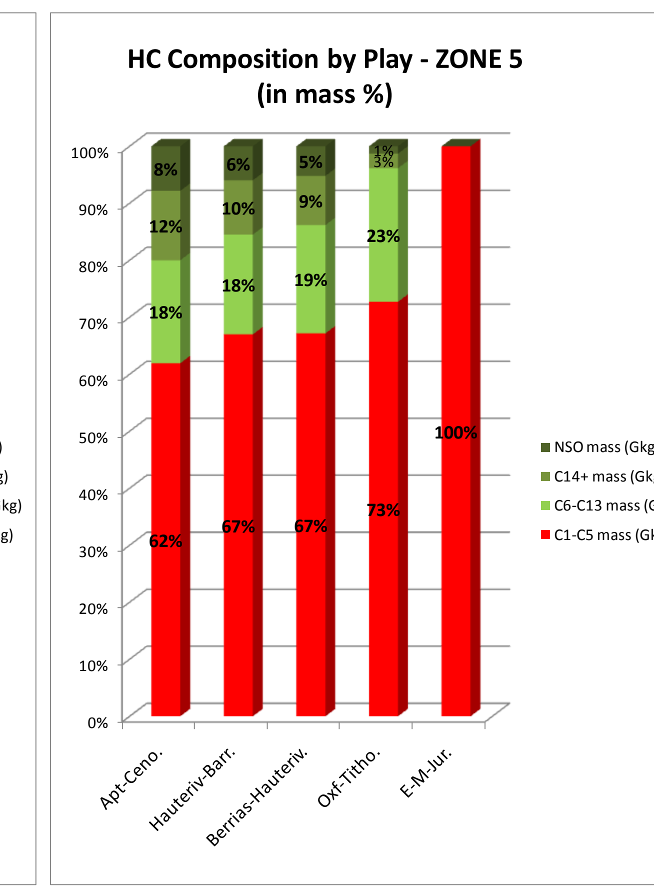


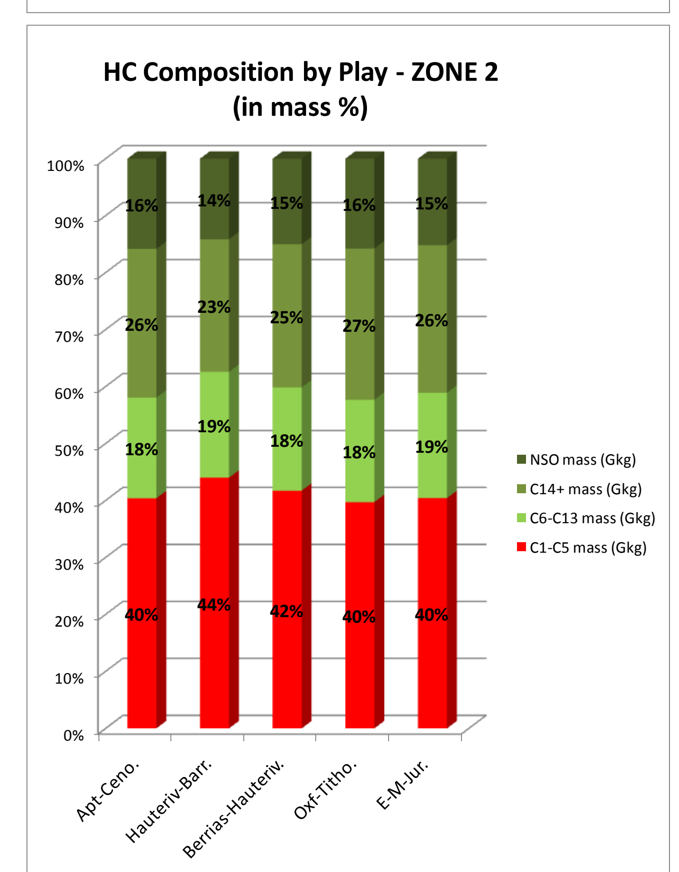


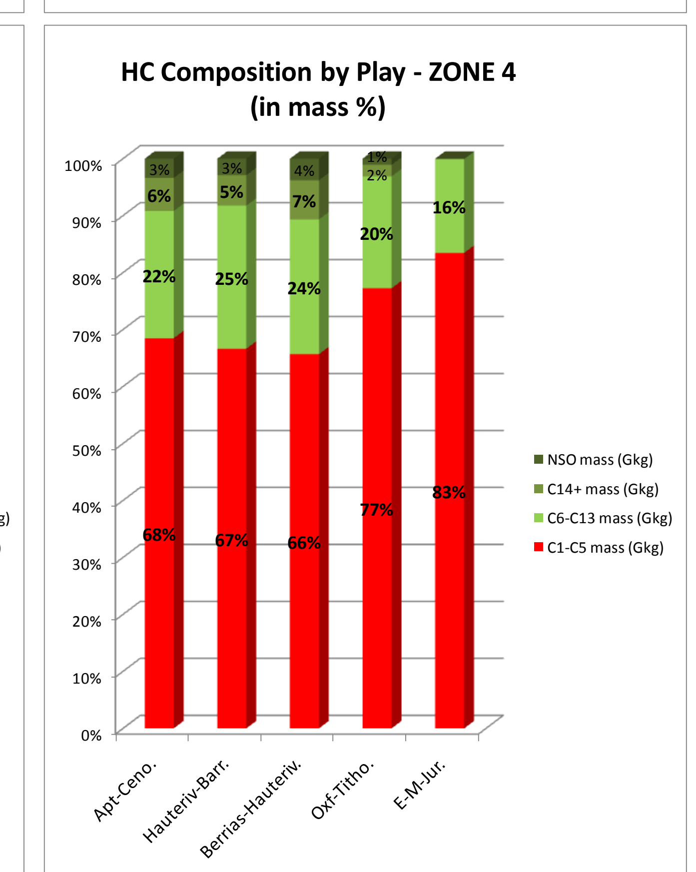
RELATIVE HC masses

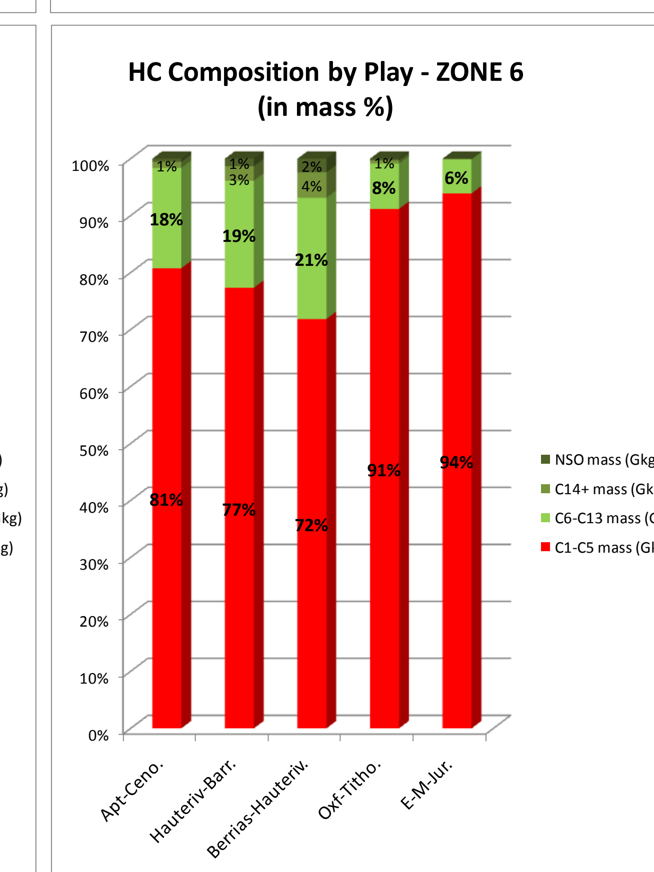




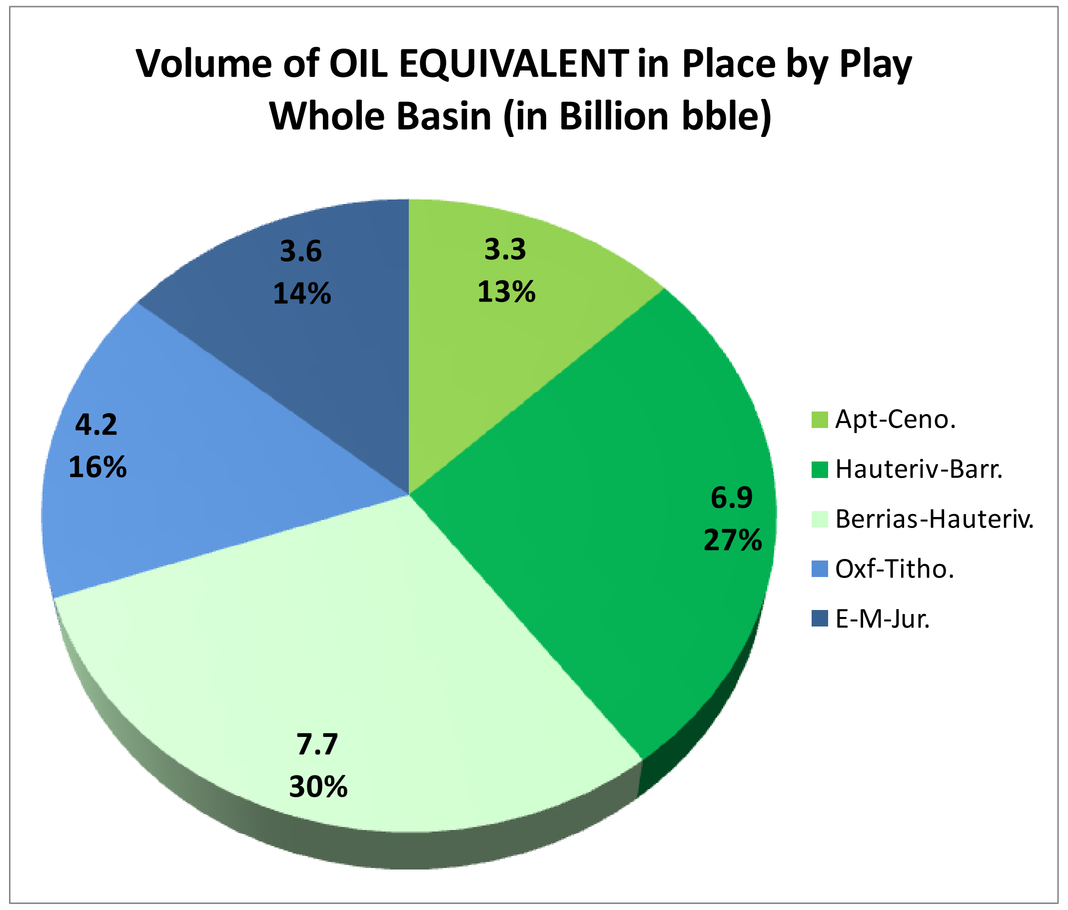


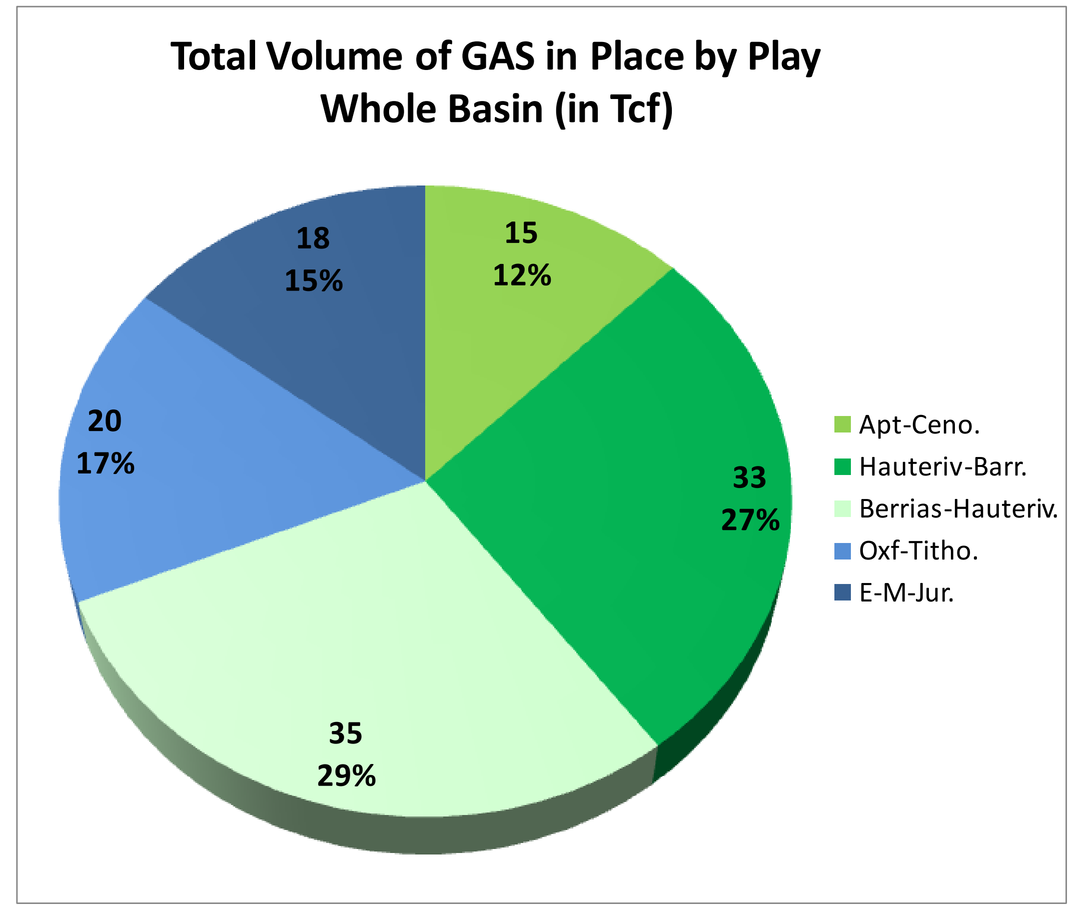


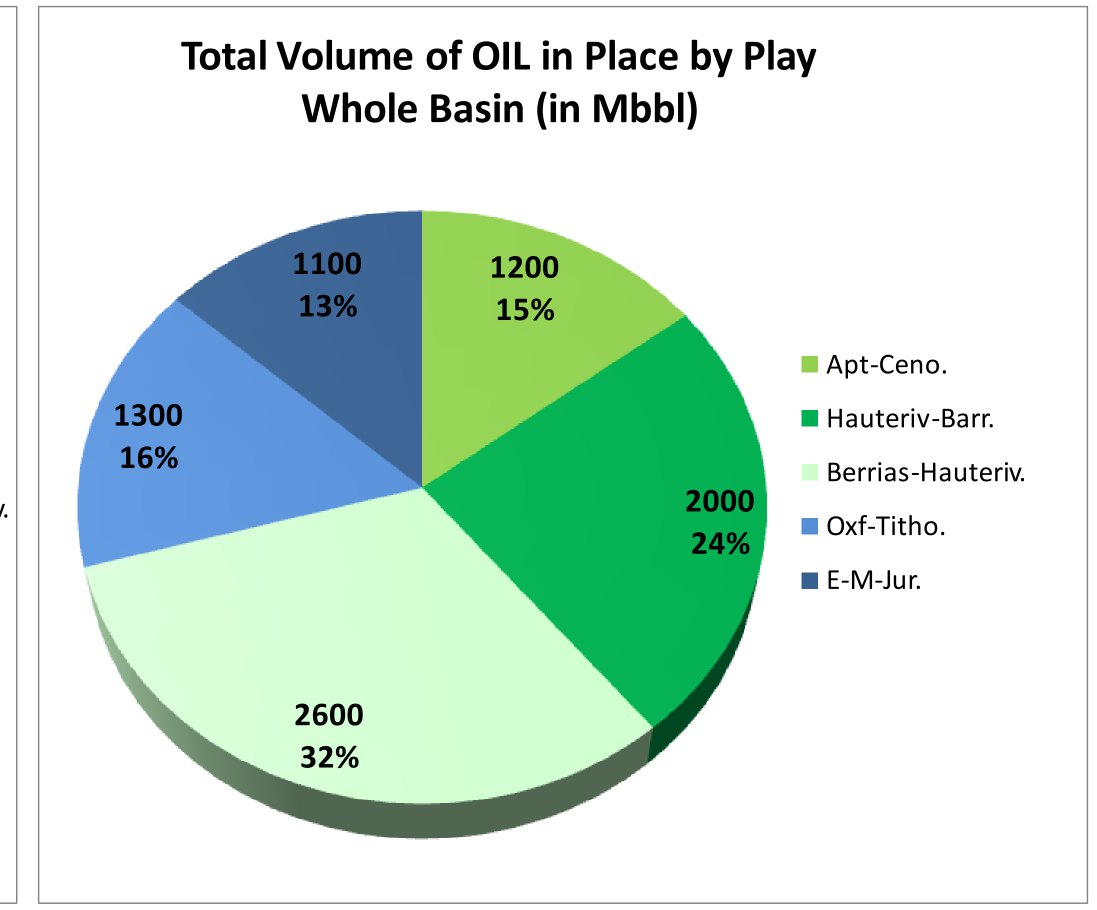


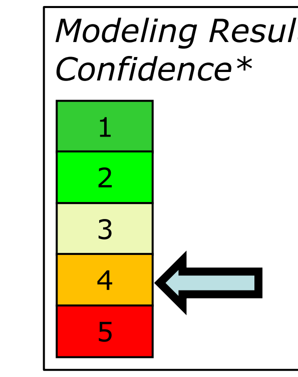


To convert HC mass (Gkg) in equivalent barrels of oil (Million bble), multiply values by about 8 (average oil density estimated at 810 kg/m³).
Masses are In Place and Unrisked.
There is no indication on the distribution of HCs within each subzone . This distribution may be heterogeneous.



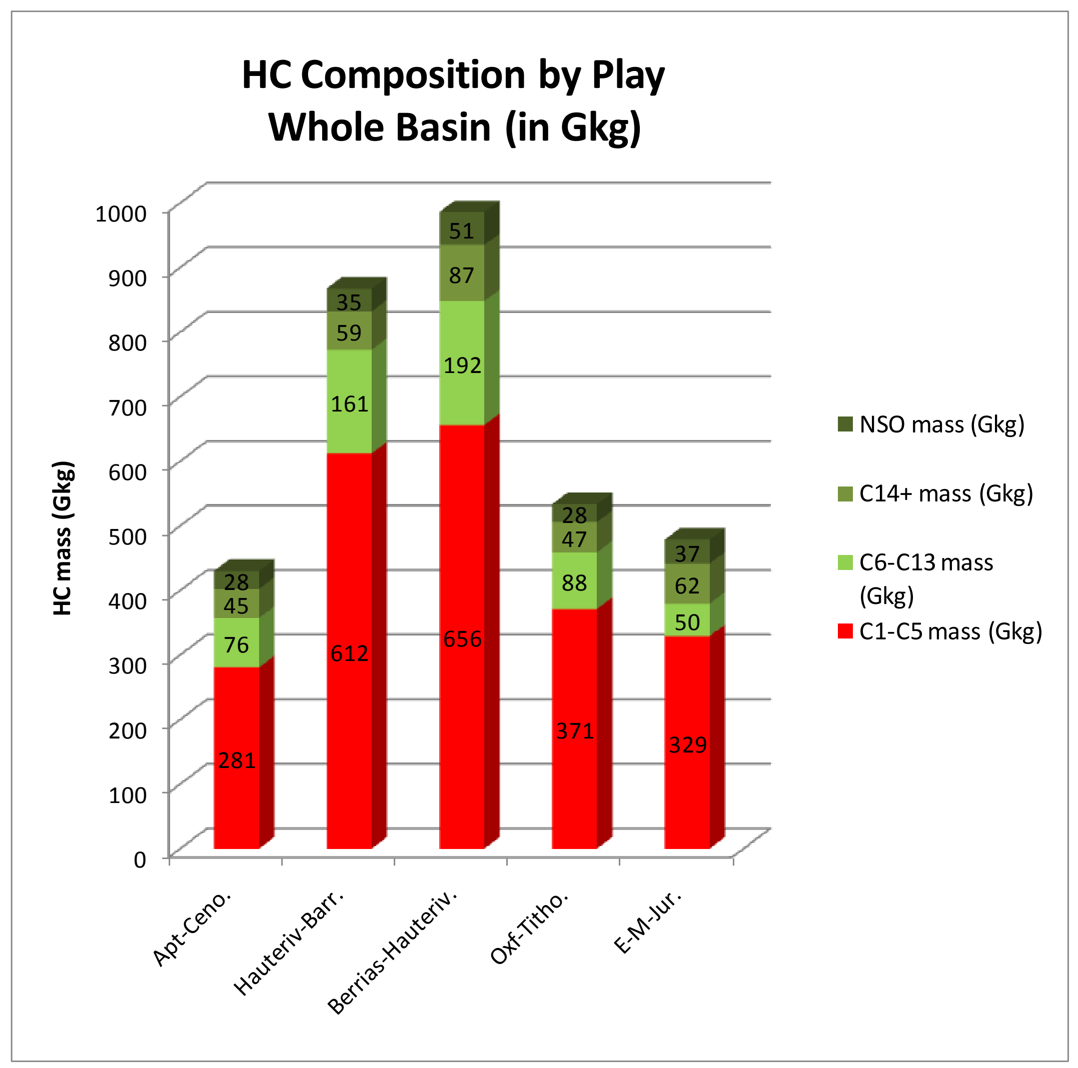


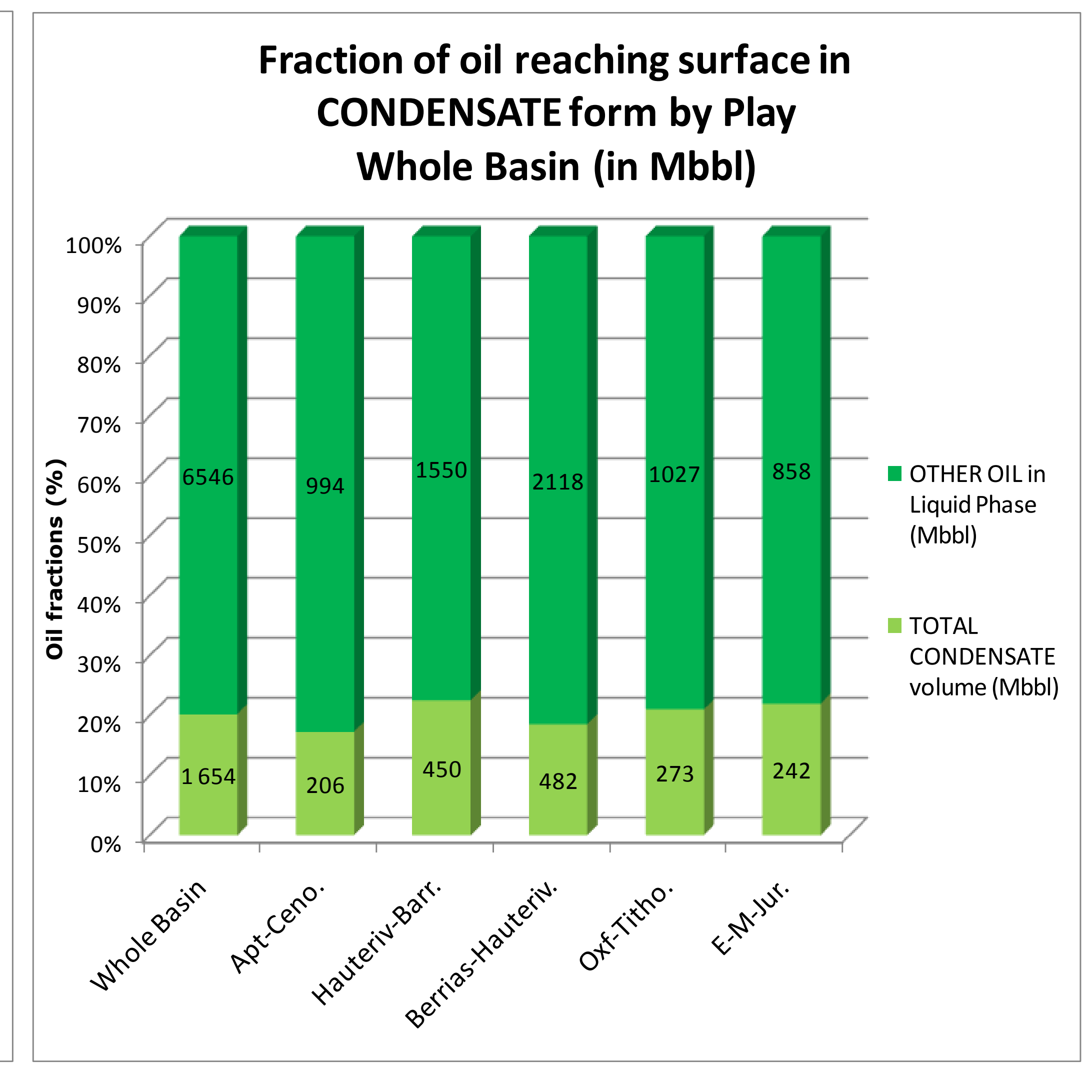




*Except for the following result which is only qualitative (5): "Fraction of oil reaching surface in CONDENSATE form". HC masses are better constrained than HC volumes.

PLAY SYSTEMS
Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J163-J150)
Early-Middle-Jurassic (J200-J163)





Synthesis by PLAY SYSTEM

Volumes are IN PLACE and UNRISKED.

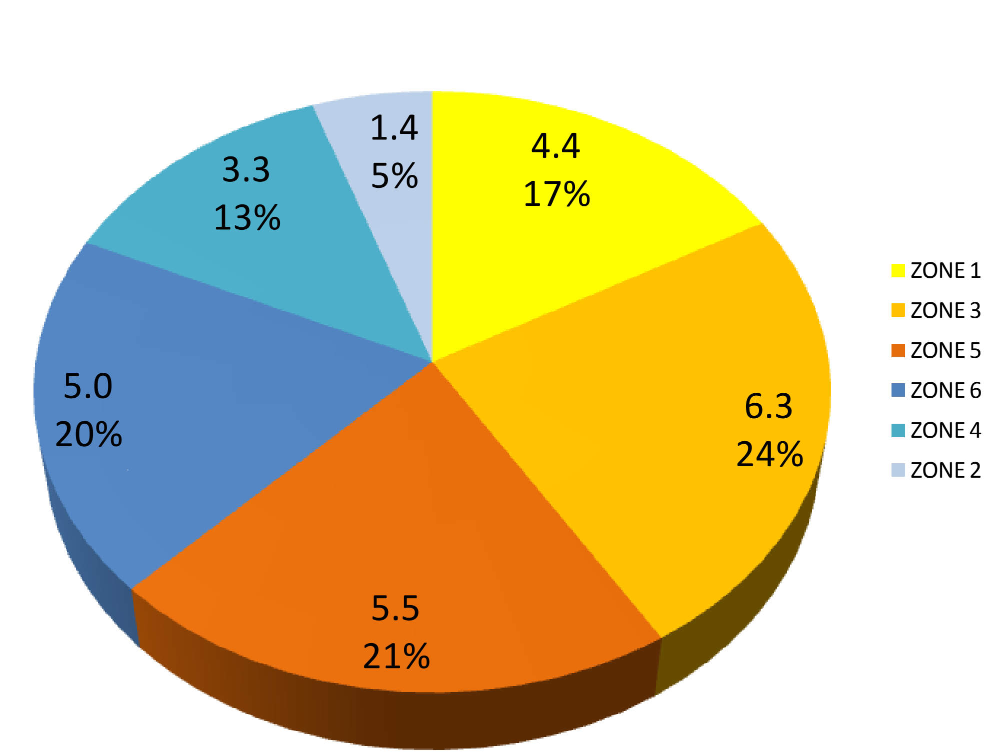
At the scale of the basin the richest plays are the Hauterivian-Barremian sequence (K130-K123) and the Berriasian-Hautrerivian sequence (J150-K130). Both plays contain about 2/3 of the total amount of HC in place. In the Sable Sub Basin, where the same distribution is observed, these sequences correspond to the Upper Mississauga and the Middle-Lower Mississauga reservoir units.

The average GOR does not significantly change between the 5 plays (about15000 scf /stb). This apparent homogeneity masks very strong contrasts between the 6 sub zones (next plate).

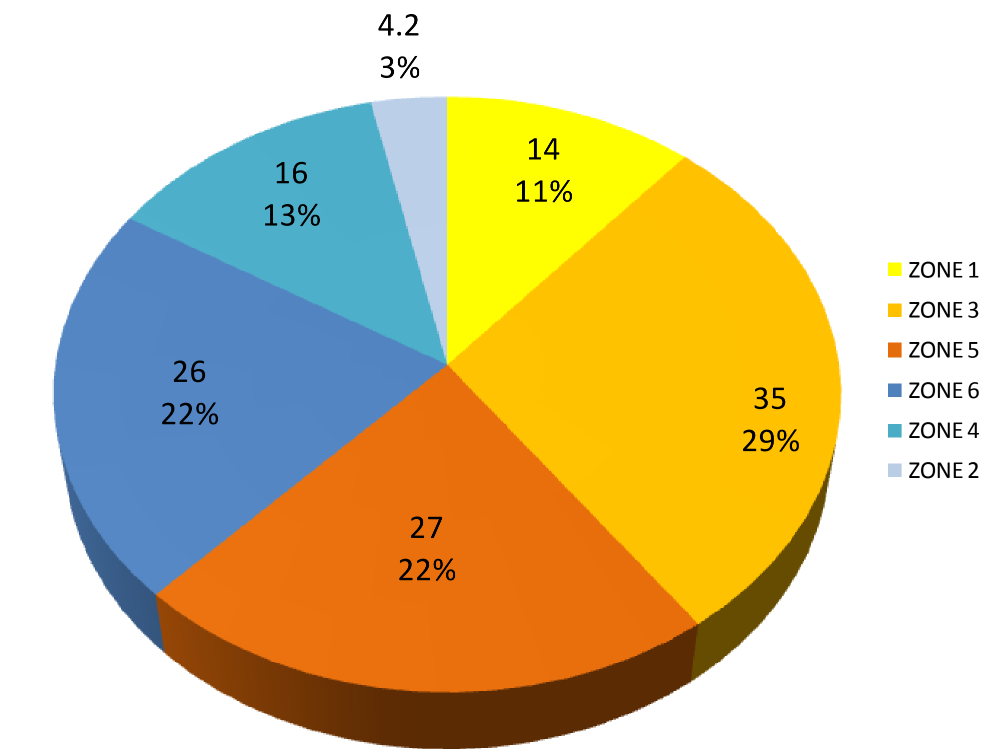
The condensate fraction is calibrated with well test data in the Sable Sub Basin. It represents about 20% of the oil in place. An average condensate density of 770-780 kg/m³ is assumed.

PLAYS WHOLE BASIN	HC MASSES IN PLACE - UNRISKED				HC VOLUMES IN PLACE - UNRISKED (surface condition)			
	TOTAL GAS mass (Gkg)	*TOTAL OIL mass (Gkg)*	*TOTAL HC mass (Gkg)*	*GORfeed (kg GAS / kg OIL)*	*TOTAL GAS volume in surface (Tcf)*	*TOTAL OIL volume in surface (Mbbl)*	*TOTAL OIL EQUIVALENT volume (Billion bble)*	*GOR (scf / stb)*
Apt-Ceno.	281	149	430	1.9	15	1200	3.3	13000
Hauteriv-Barr.	612	255	867	2.4	33	2000	6.9	16000
Berrias-Hauteriv.	656	330	986	2.0	35	2600	7.7	14000
Oxf-Titho.	371	162	534	2.3	20	1300	4.2	15000
E-M-Jur.	329	150	479	2.2	18	1100	3.6	16000
TOTAL	2250	1046	3295	2.2	121	8200	26	14800

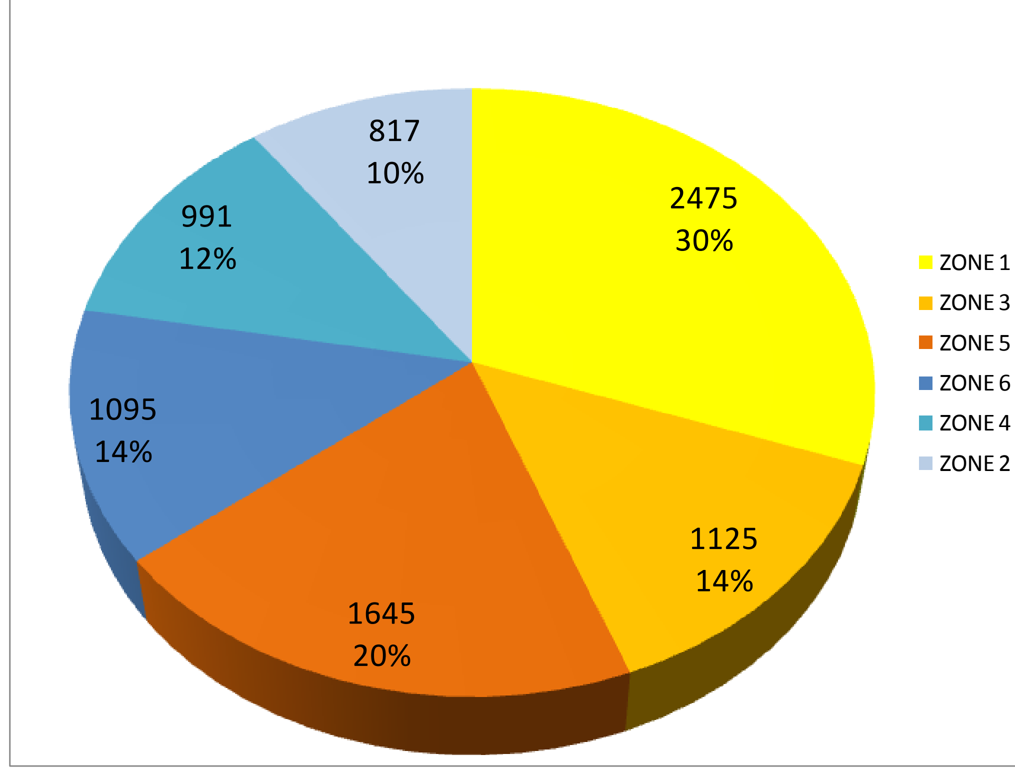
Volume of OIL EQUIVALENT in Place by Zone All Plays (in Billion bble)

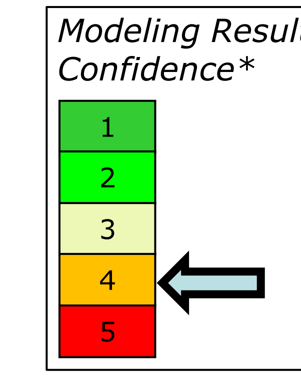


Total Volume of GAS in Place by Zone All Plays (in Tcf)

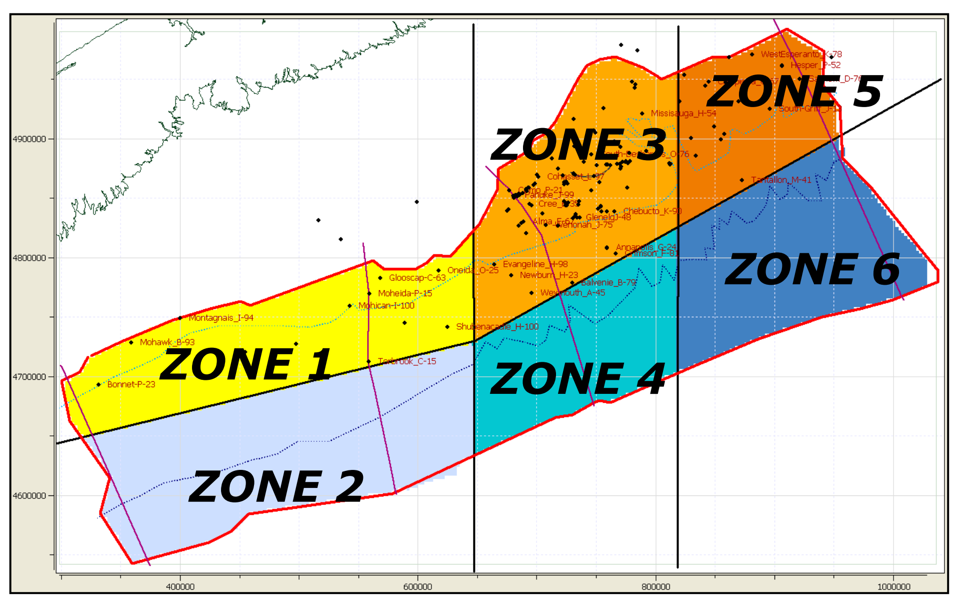


Total Volume of OIL in Place by Zone All Plays (in Mbbl)

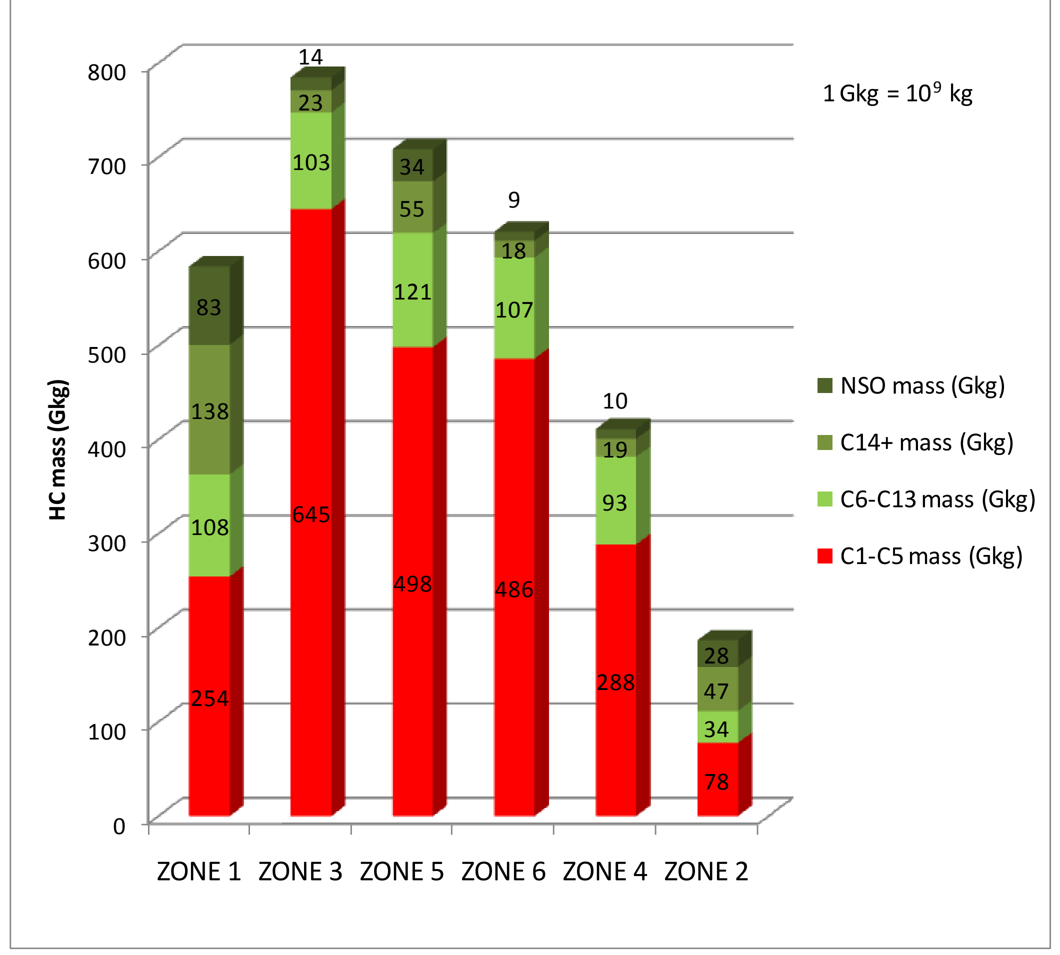




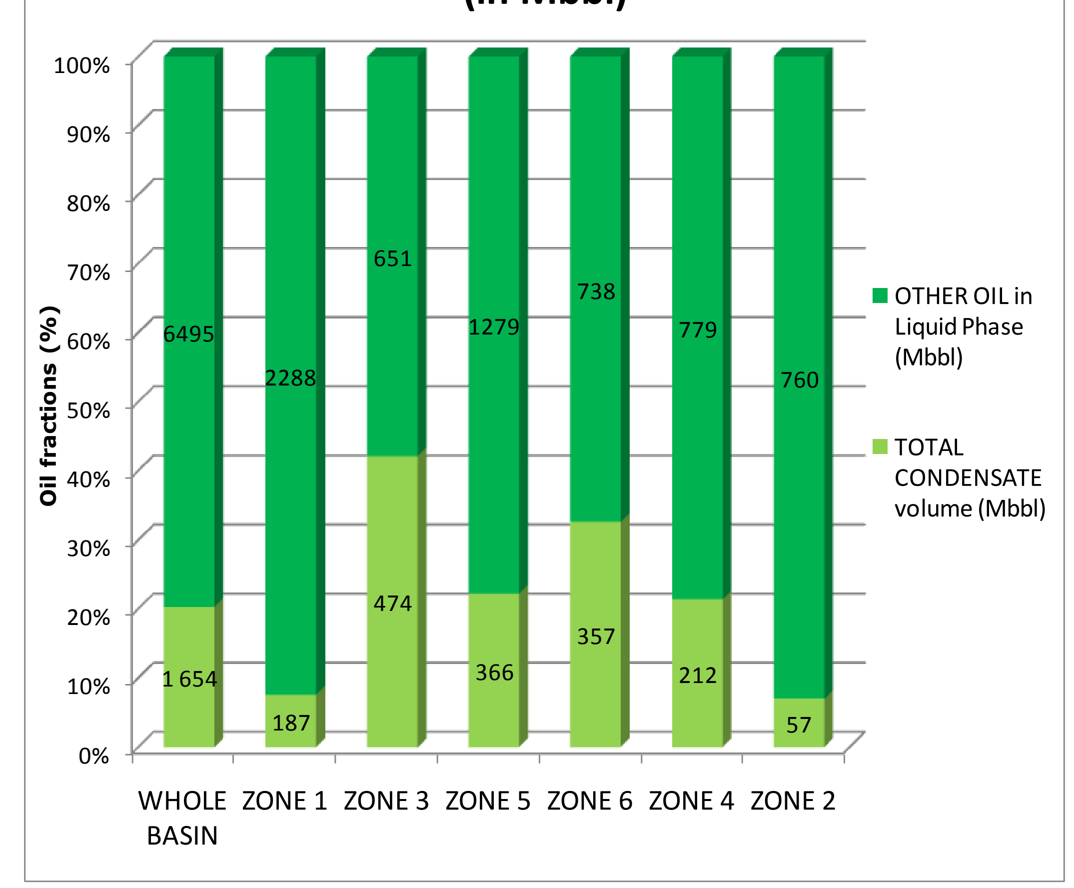
*Except for the following result which is only qualitative (5): "Fraction of oil reaching surface in CONDENSATE form". HC masses are better constrained than HC volumes.



HC Type by Zone - All Plays (in 10^9 kg)



Fraction of oil reaching surface in CONDENSATE form by Zone - All Plays (in Mbbl)



Synthesis by ZONE

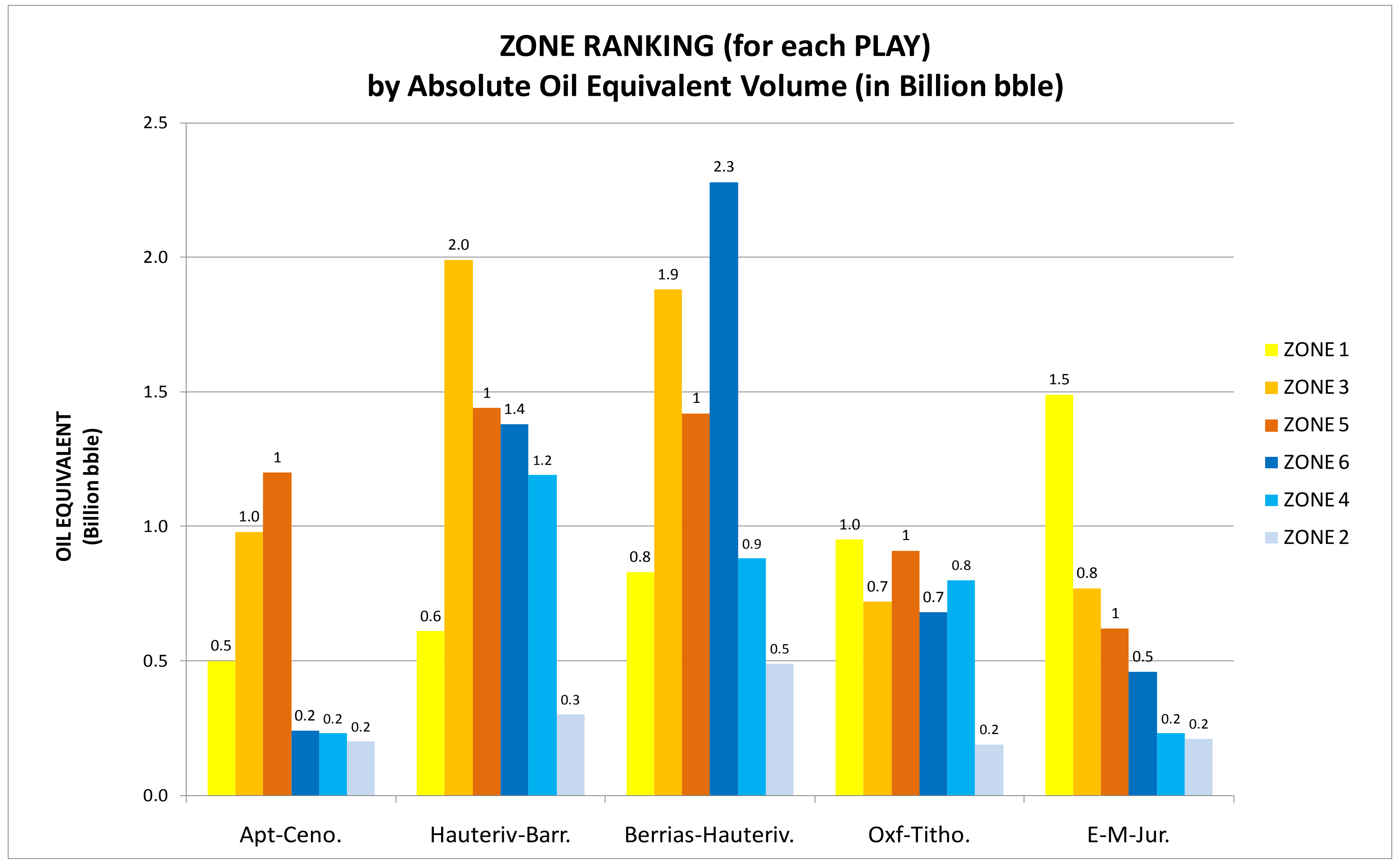
Volumes are IN PLACE and UNRISKED (surface conditions).
No indication on the distribution of HCs within each subzone.

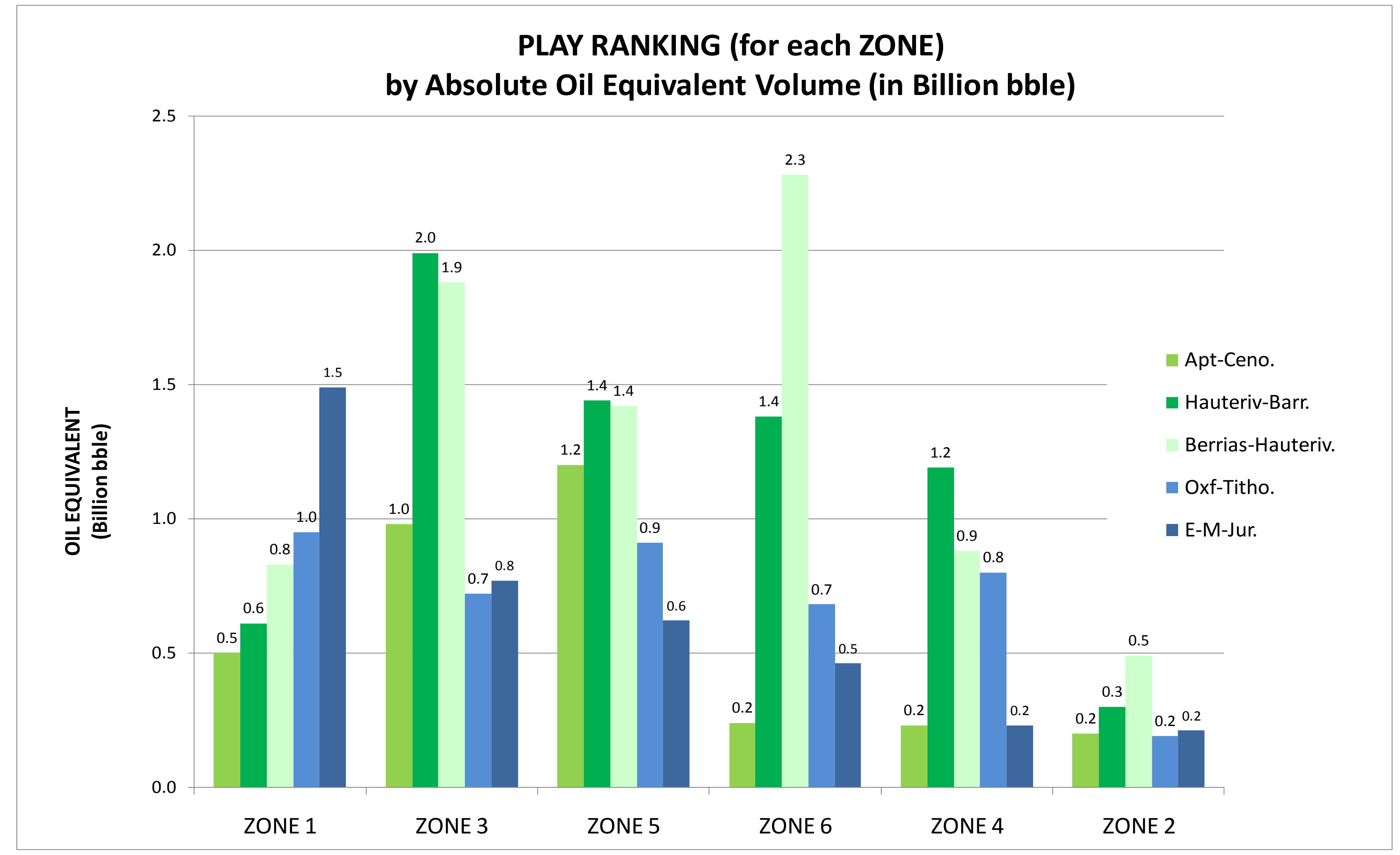
The richest zone is Zone 3 which contains the Sable Sub-basin (about 1/4 of the total calculated amount of HC In Place. The poorest zones are Zone 4 and Zone 2. About 2/3 of the total amount of HC in place are in "shelf zones" (1, 3, 5): Except Zone 6 where turbidites can be more abundant, and where salt diapirs do not dramatically affect drainage areas, "basin zones" would be less prospective than "shelf zones".

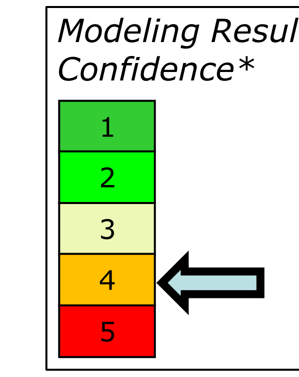
The average GOR change between the 6 zones (between 5000 and 25000 scf /stb). Zone 3 and 6 are particularly rich in gas, while zone 1 and 2 contain more oil than gas. Such differences come from changes in maturity / secondary cracking intensity, and in SR contributions. As a consequence about 1/3 of the oil in place at the scale of the basin would be trapped in Zone 1.

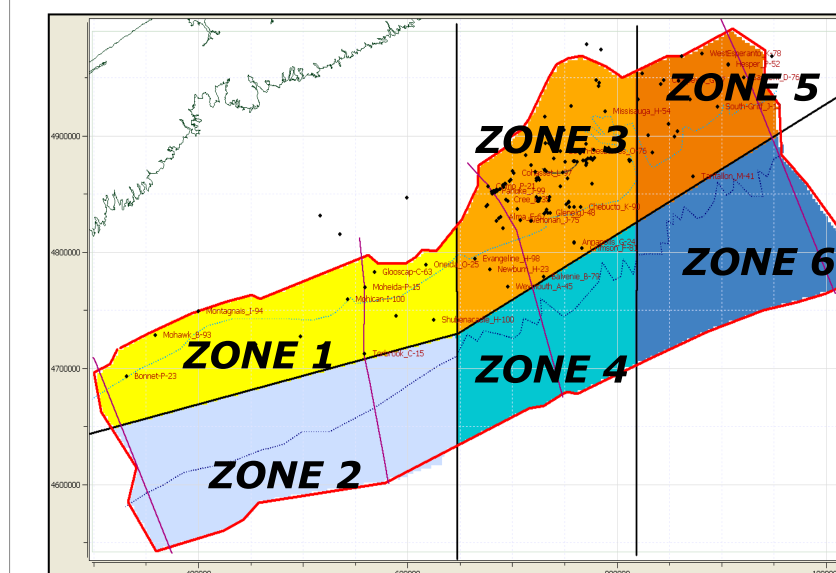
The condensate fraction is calibrated with well test data in the Sable Sub Basin. It represents about 20% of the oil in place (up to 40% in the Zone 3 – Sable Sub Basin). An average condensate density of 770-780 kg/m³ is assumed.

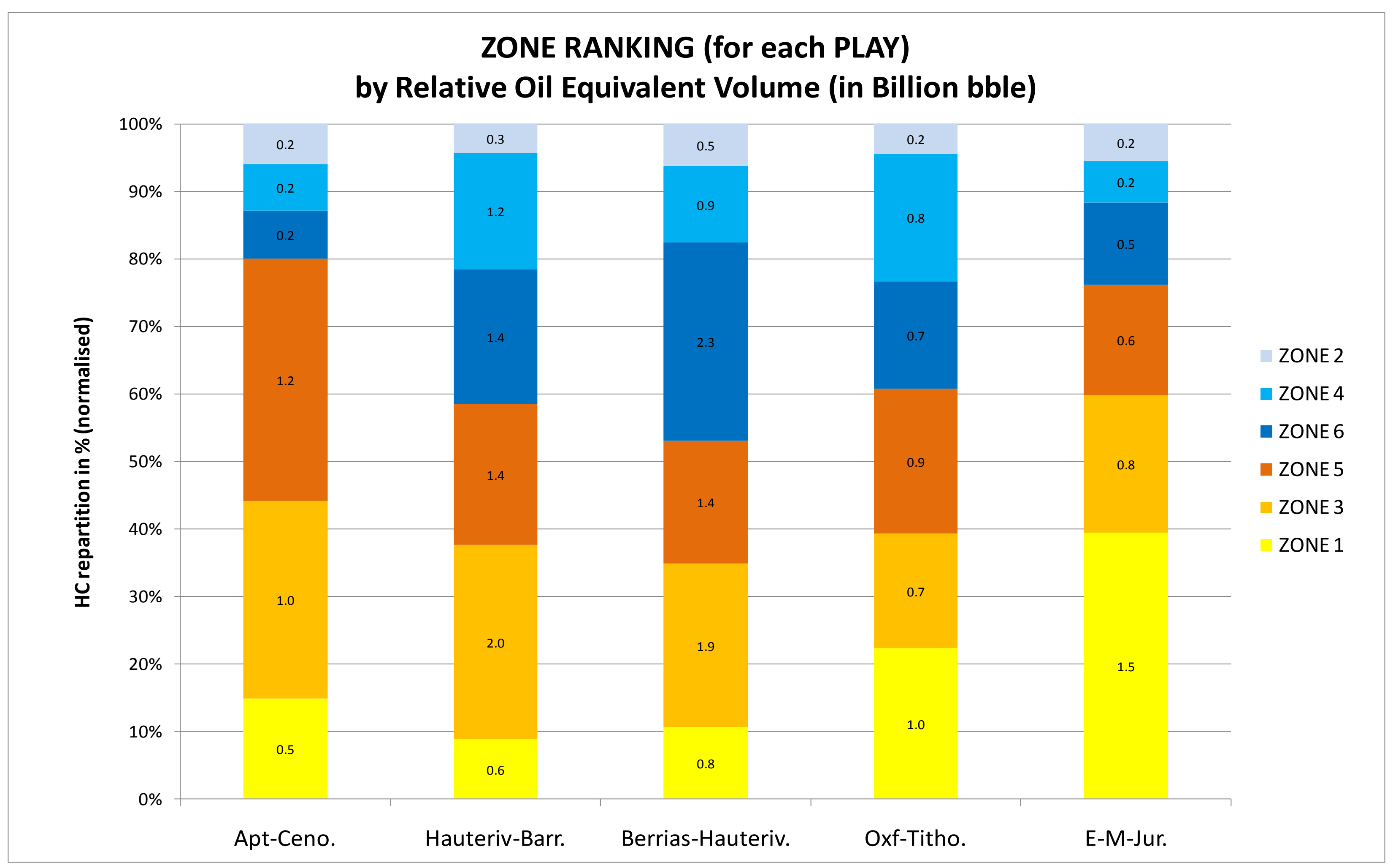
	HC MASSES IN PLACE - UNRISKED				HC VOLUMES IN PLACE - UNRISKED (surface condition)			
By ZONE	*TOTAL GAS mass (Gkg)*	*TOTAL OIL mass (Gkg)*	*TOTAL HC mass (Gkg)*	*GORfeed (kg GAS / kg OIL)*	*TOTAL GAS volume in surface (Tcf)*	*TOTAL OIL volume in surface (Mbbl)*	*TOTAL OIL EQUIVALENT volume (Billion bble)*	*GOR (scf / stb)*
ZONE 1	254	329	584	0.8	14	2470	4.4	6000
ZONE 3	645	140	785	4.6	35	1130	6.3	31000
ZONE 5	498	210	708	2.4	27	1650	5.5	16000
ZONE 6	486	135	621	3.6	26	1090	5.0	24000
ZONE 4	288	123	411	2.4	16	990	3.3	16000
ZONE 2	78	109	187	0.7	4.2	820	1.4	5000
Whole Basin	**2250**	**1046**	**3295**	**2.2**	**121**	**8150**	**26**	**15000**

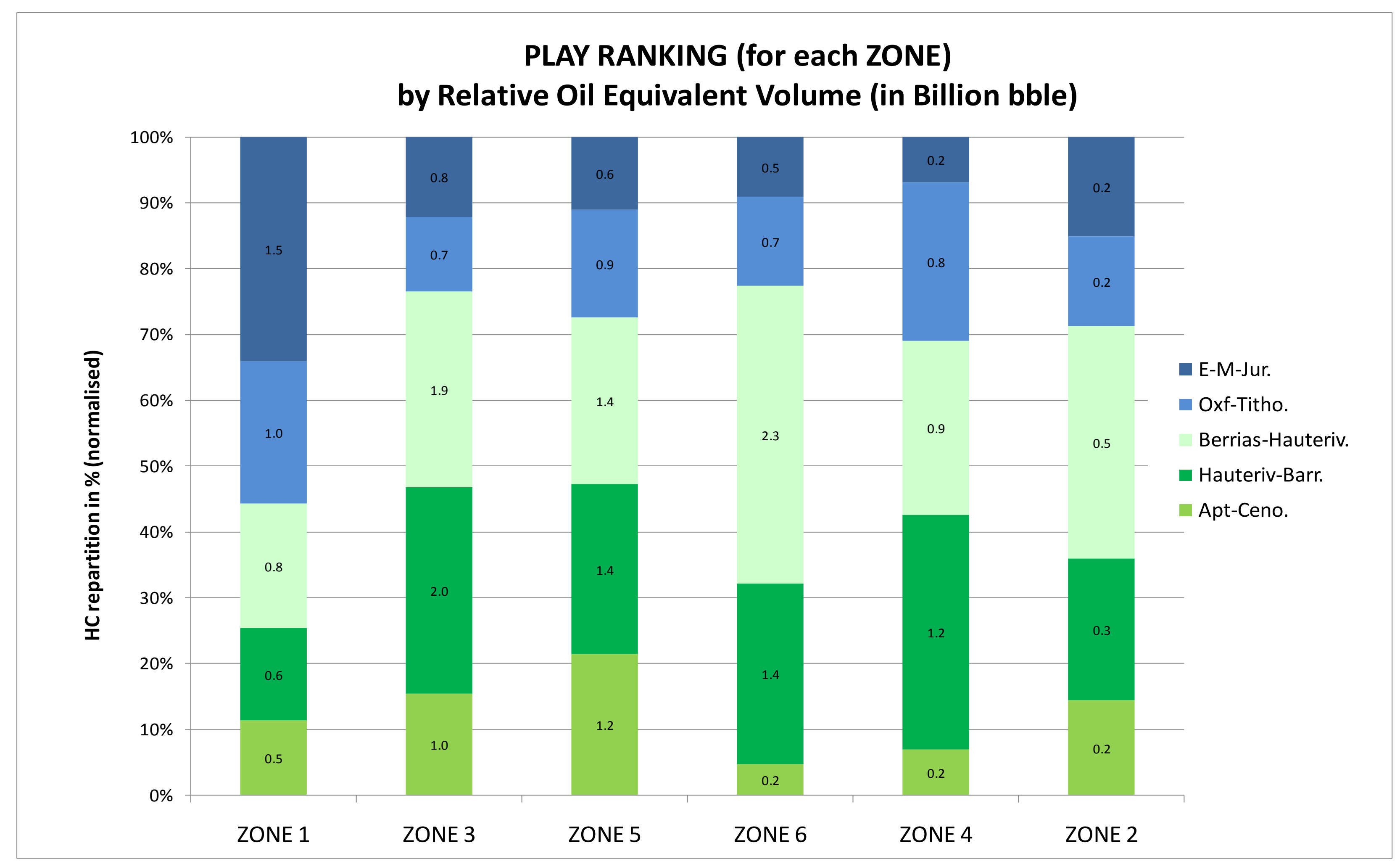












PLAY SYSTEMS
Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J163-J150)
Early-Middle-Jurassic (J200-J163)

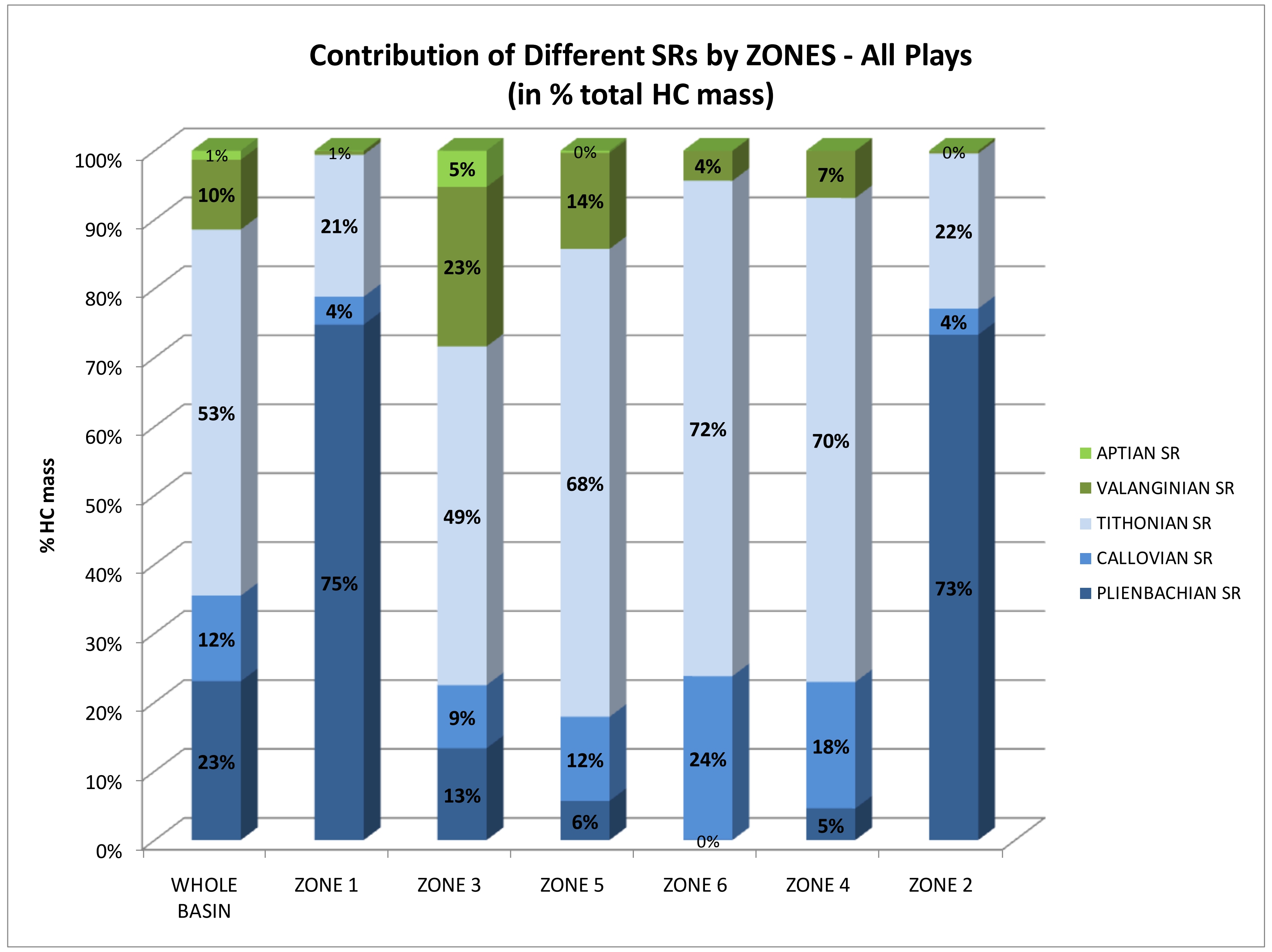
TOTAL OIL EQUIVALENT UNRISKED VOLUME (Billion bble)	ZONE 1	ZONE 3	ZONE 5	ZONE 6	ZONE 4	ZONE 2	Whole Basin
Apt-Ceno.	0.5	1.0	1.2	0.2	0.2	0.2	3.3
Hauteriv-Barr.	0.6	2.0	1.4	1.4	1.2	0.3	6.9
Berrias-Hauteriv.	0.8	1.9	1.4	2.3	0.9	0.5	7.7
Oxfordian-Tithonian	0.9	0.7	0.9	0.7	0.8	0.2	4.2
E-M-Jur.	1.5	0.8	0.6	0.5	0.2	0.2	3.6
TOTAL	4.4	6.3	5.6	5.0	3.3	1.4	26

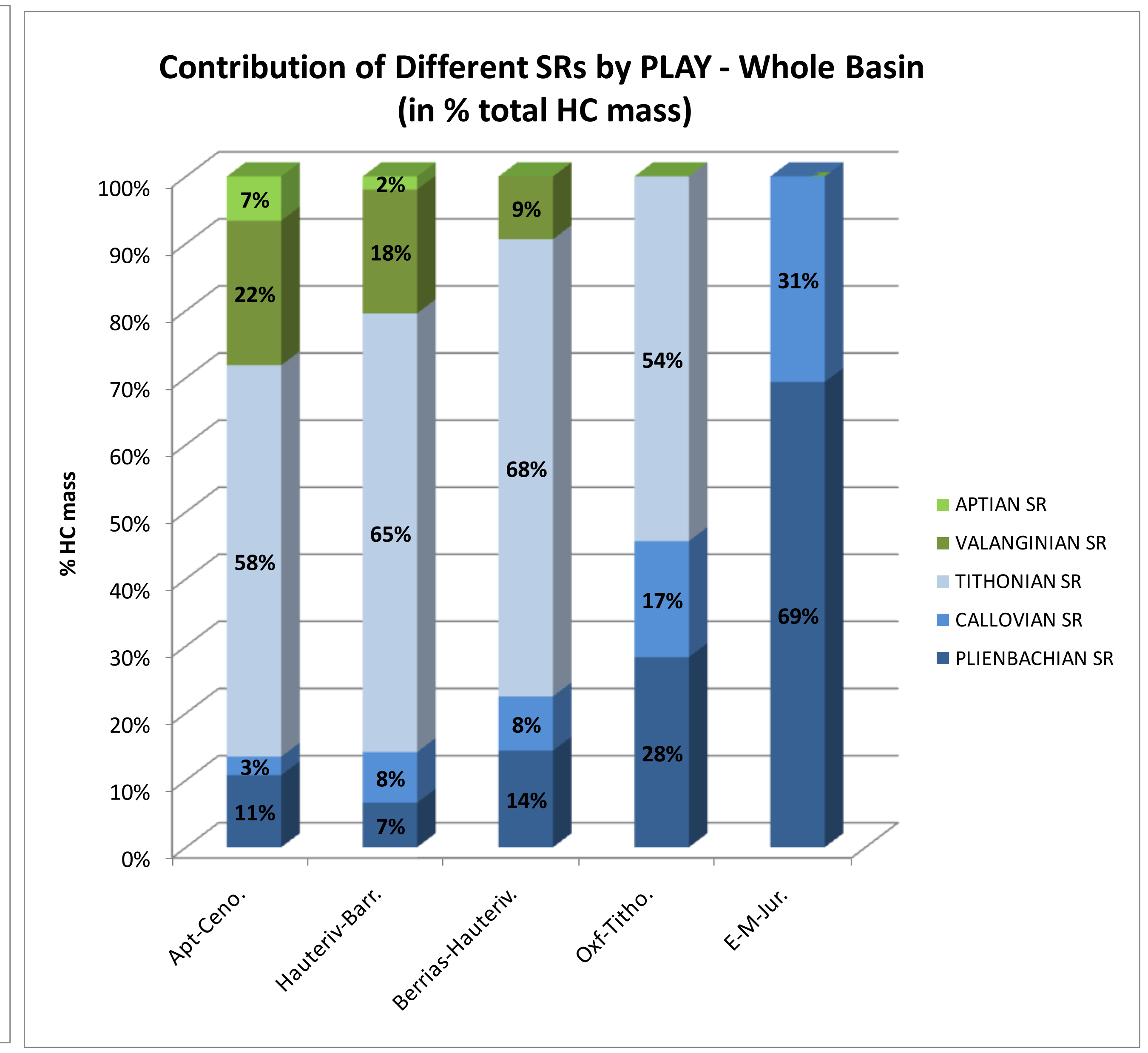
PLAY SYSTEMS and ZONES rankings

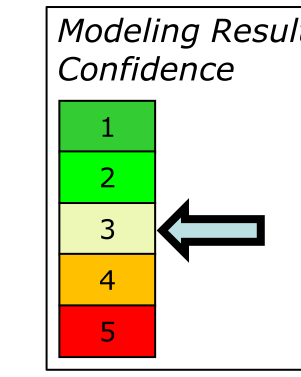
Volumes are IN PLACE and UNRISKED (surface conditions).
No indication on the distribution of HCs within each subzone.

Zone ranking changes in function with the Play considered. The most significant features are:
- Zones 3 and 5 have first ranks in Albian-Cenomanian and Hauterivian-Barremian play systems.
- Zone 6 reaches the first rank in the Berriasian-Hauterivian play system.
- Zone 1 reaches the first rank for Oxfordian-Tithonian and Early-Middle Jurassic play systems.

Play ranking in function with the Zone considered reflects the same tendencies.







Source Rocks Contributions

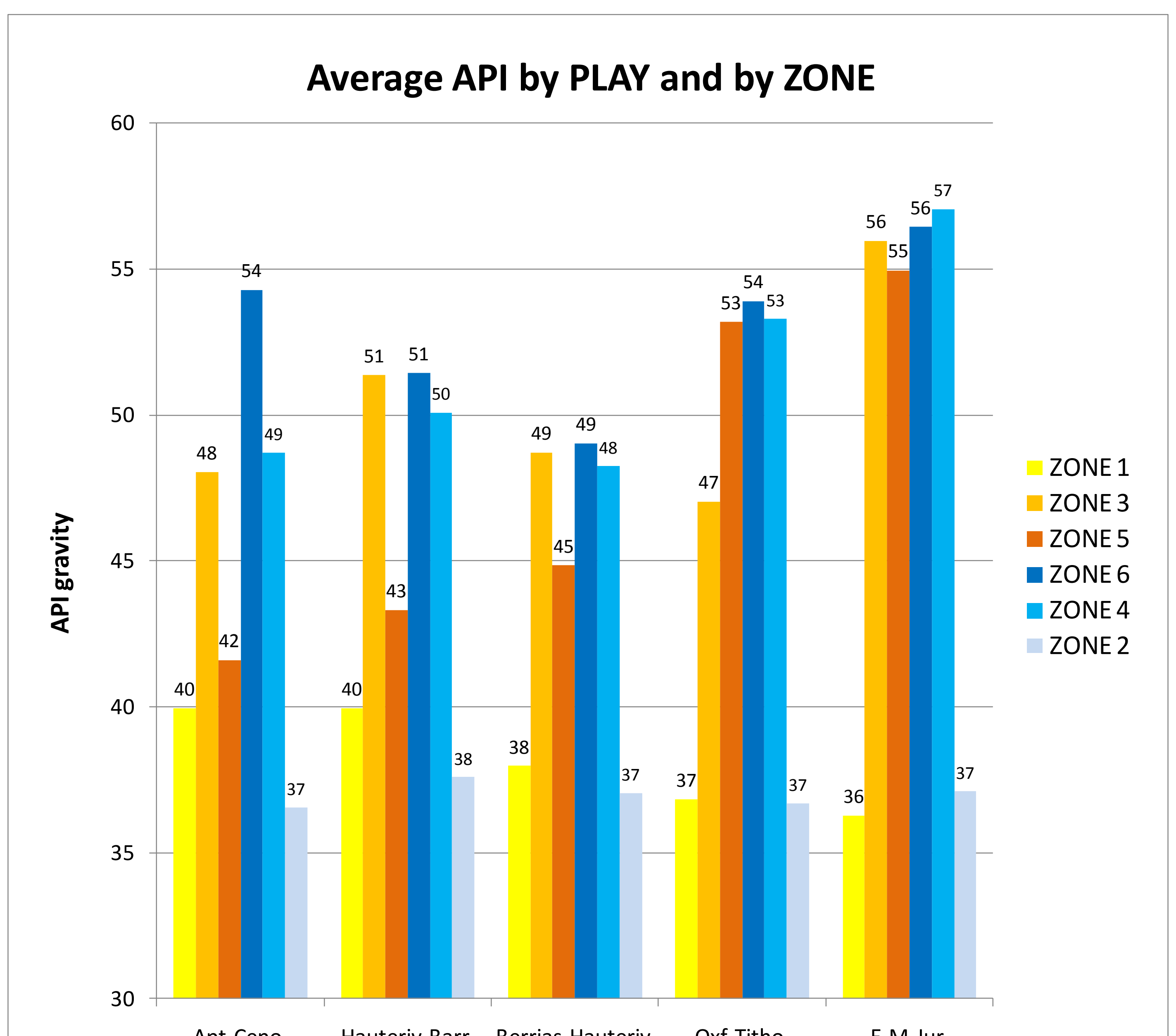
Source rocks contributions depend on four phenomenon: (1) maturity levels of SRs; (2) hydrocarbon potentials of SRs, (3) "migration efficiencies" (partly related to the distance between the SR and the reservoir, the "upward" or "downward" migration); (4) complex timings between SRs expulsion and traps formation.

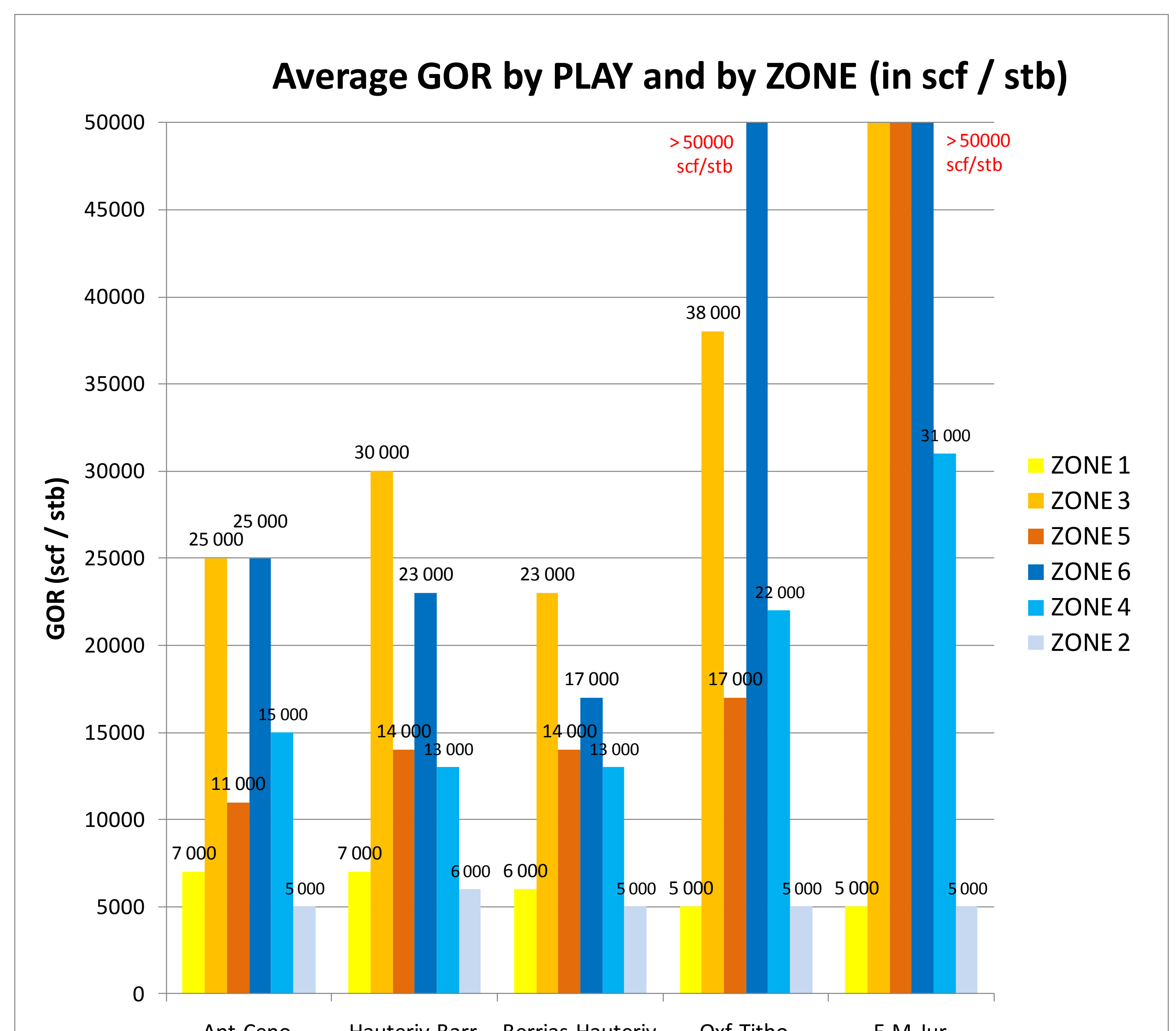
Cretaceous Source Rocks are not significant contributors except in Zone 3 where Valanginian SR and Aptian SR feed Aptian-Cenomanian and Hauterivian-Barremian play systems, up to 1/4 of the total amount of hydrocarbon in place.

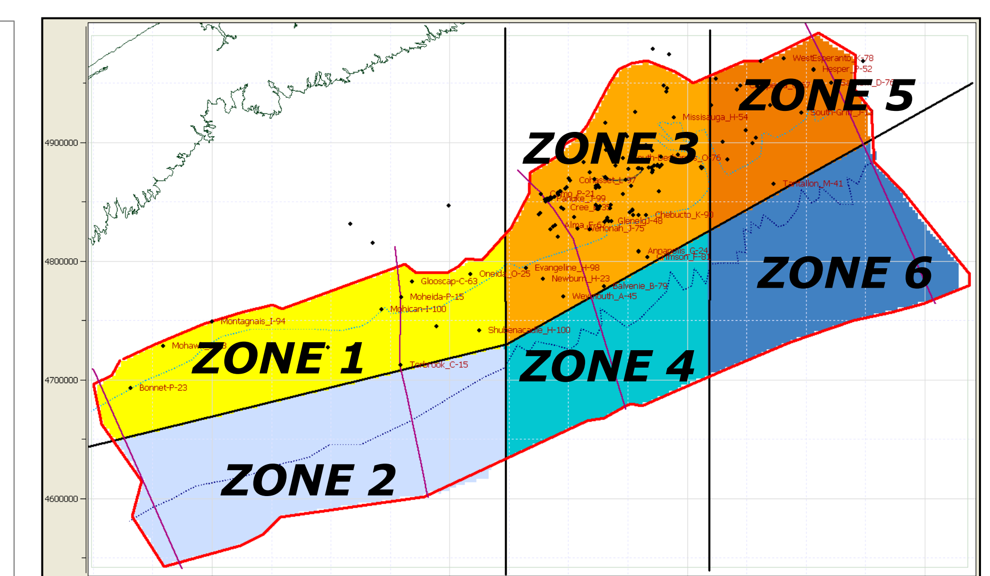
The ***Tithonian SR*** is a significant contributor in all zones, all play systems (except the Early-Middle-Jurassic play system). At the scale of the basin it sources 1/2 of the total amount of hydrocarbon in place.

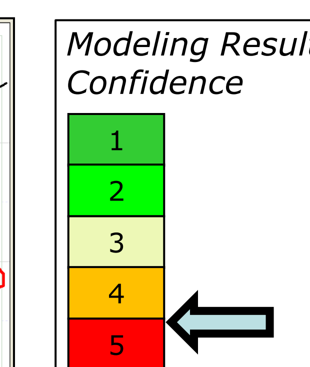
The ***Callovian SR*** is not a significant contributor, except maybe in Zone 6, and in Early-Middle-Jurassic play system.

The ***Pliensbachian SR*** is locally a very significant SR (up to 3/4 of the total amount of hydrocarbon in place in zones 1 and 2). It feeds mainly Oxfordian-Tithonian and Early-Middle-Jurassic play systems where its maturity is not excessive.









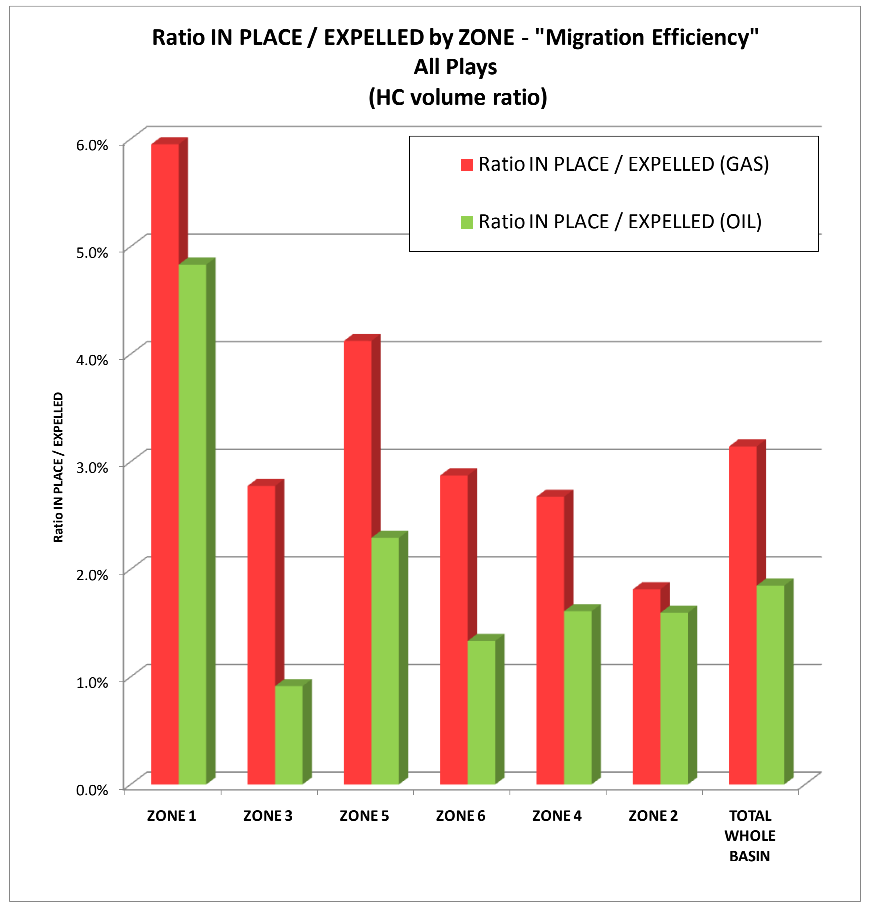
API and Gas Oil Ratio

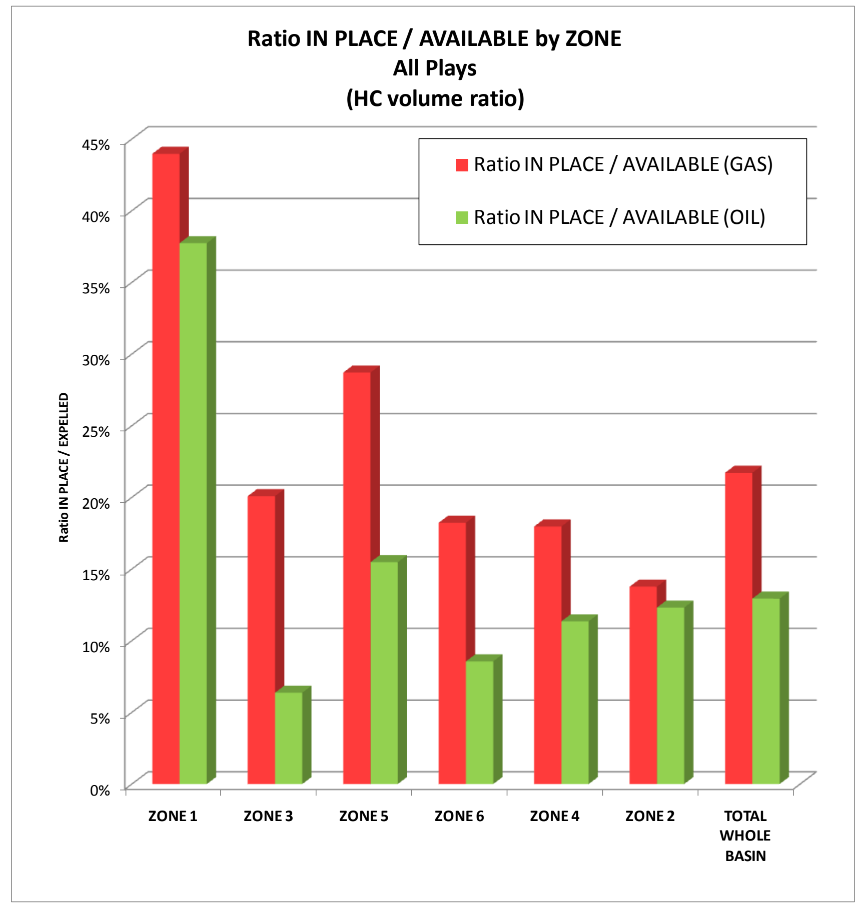
API gravity varies significantly between plays and zones. Except in zones 1 and 2 where maturity levels are lower, the highest API values are found in the deepest play systems (Oxfordian-Tithonian and Early-Middle-Jurassic). This is mainly due to secondary cracking in reservoirs.

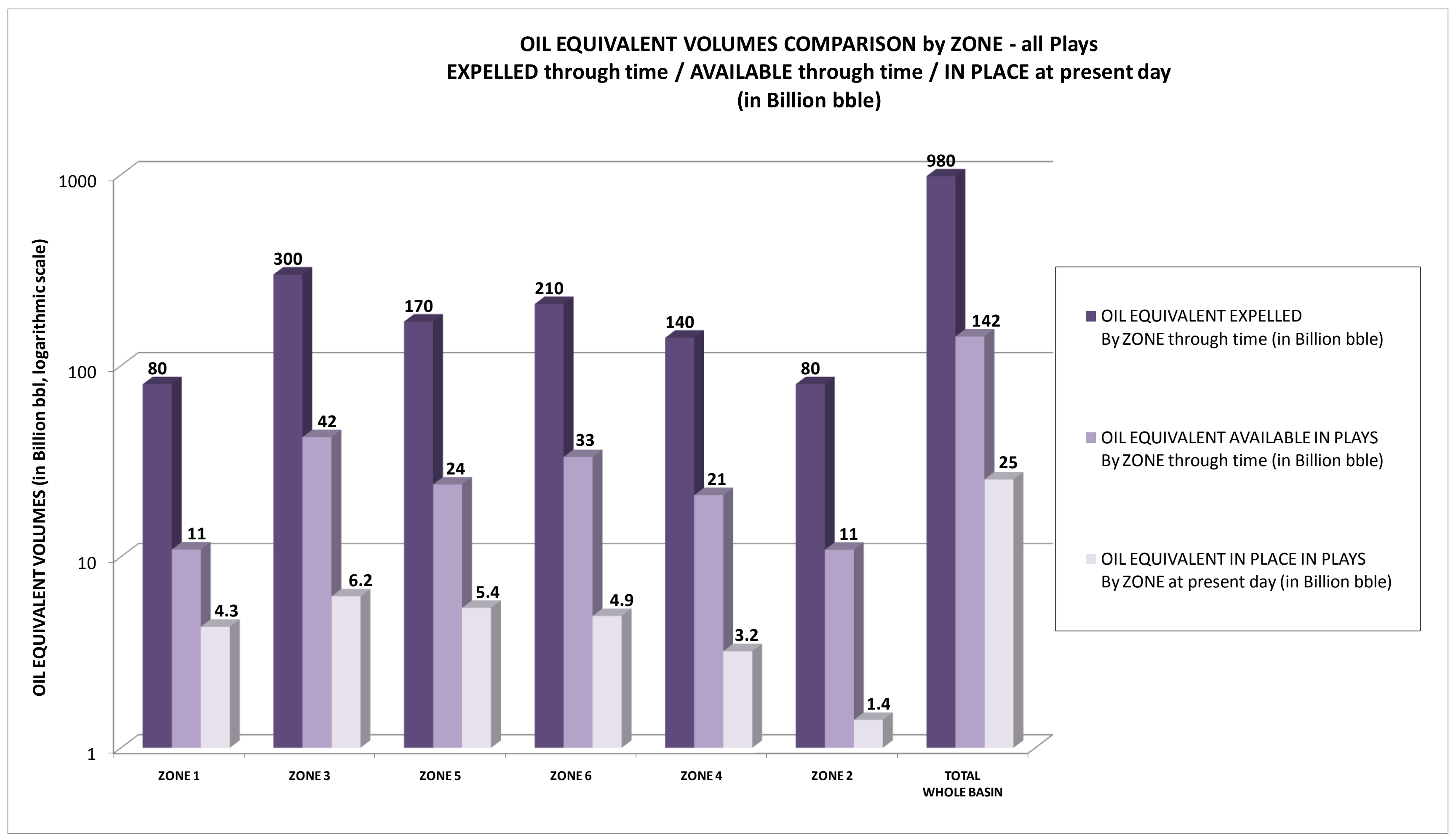
Except in Zone 5, API values increase also in Cretaceous play systems (Hauterivian-Barremian and/or Aptian-Cenomanian) despite a lower maturity of near source rocks. This is the consequence of two phenomena: (1) the higher contribution of Cretaceous/Upper Jurassic gas prone source rocks; (2) the late trap formation in Cretaceous play systems versus early source rock maturity and hydrocarbon expulsion.

GOR values are correlated with API values and depend on the same processes. The lowest GOR are found in zones 1 and 2, the highest GOR are found in zone 3 and 6. Extremely high GOR exist in the Early-Middle-Jurassic play system: in this sequence there is only gas in zones 3, 5, and 6 (ultimate stage of secondary cracking).

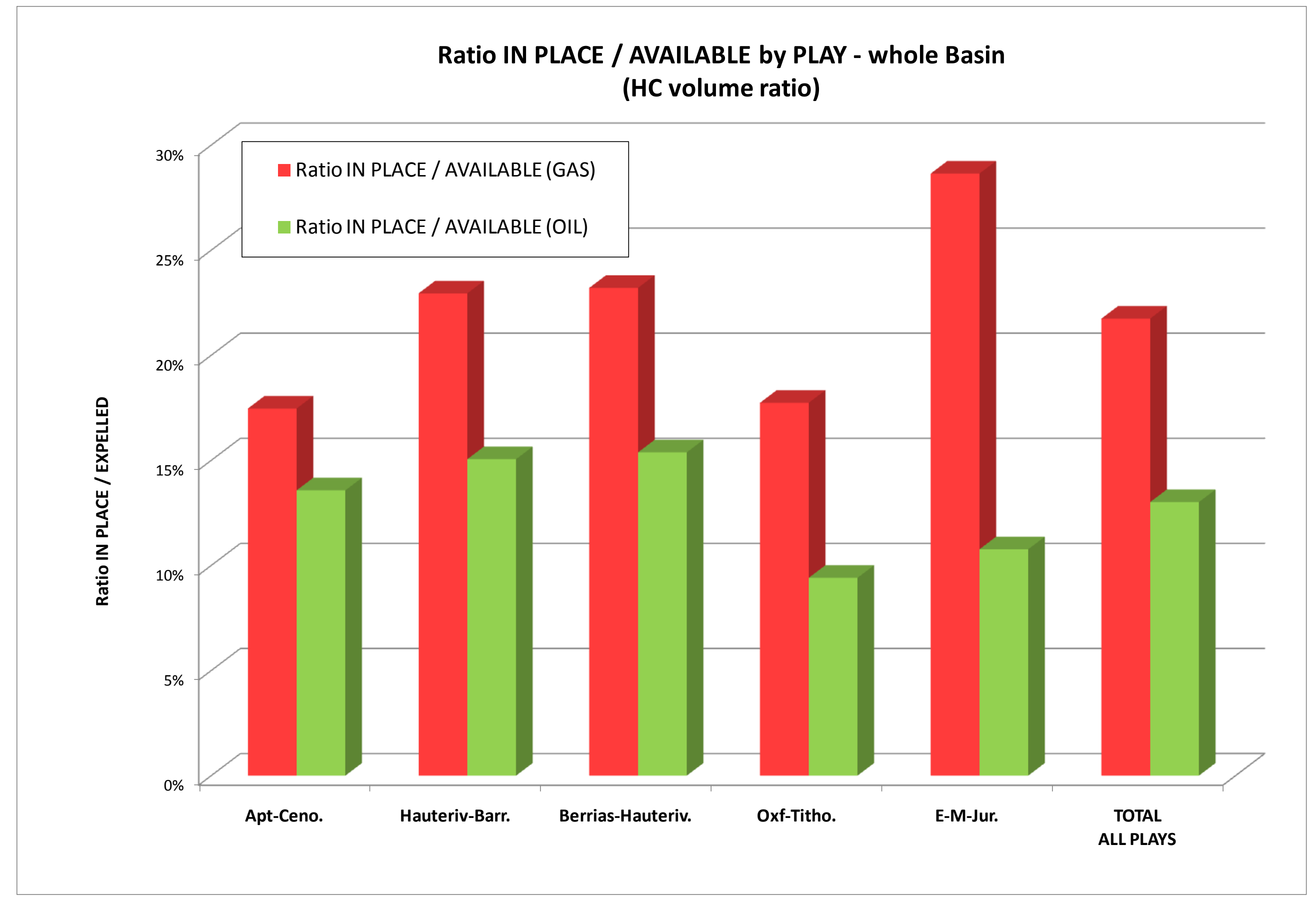
By ZONE

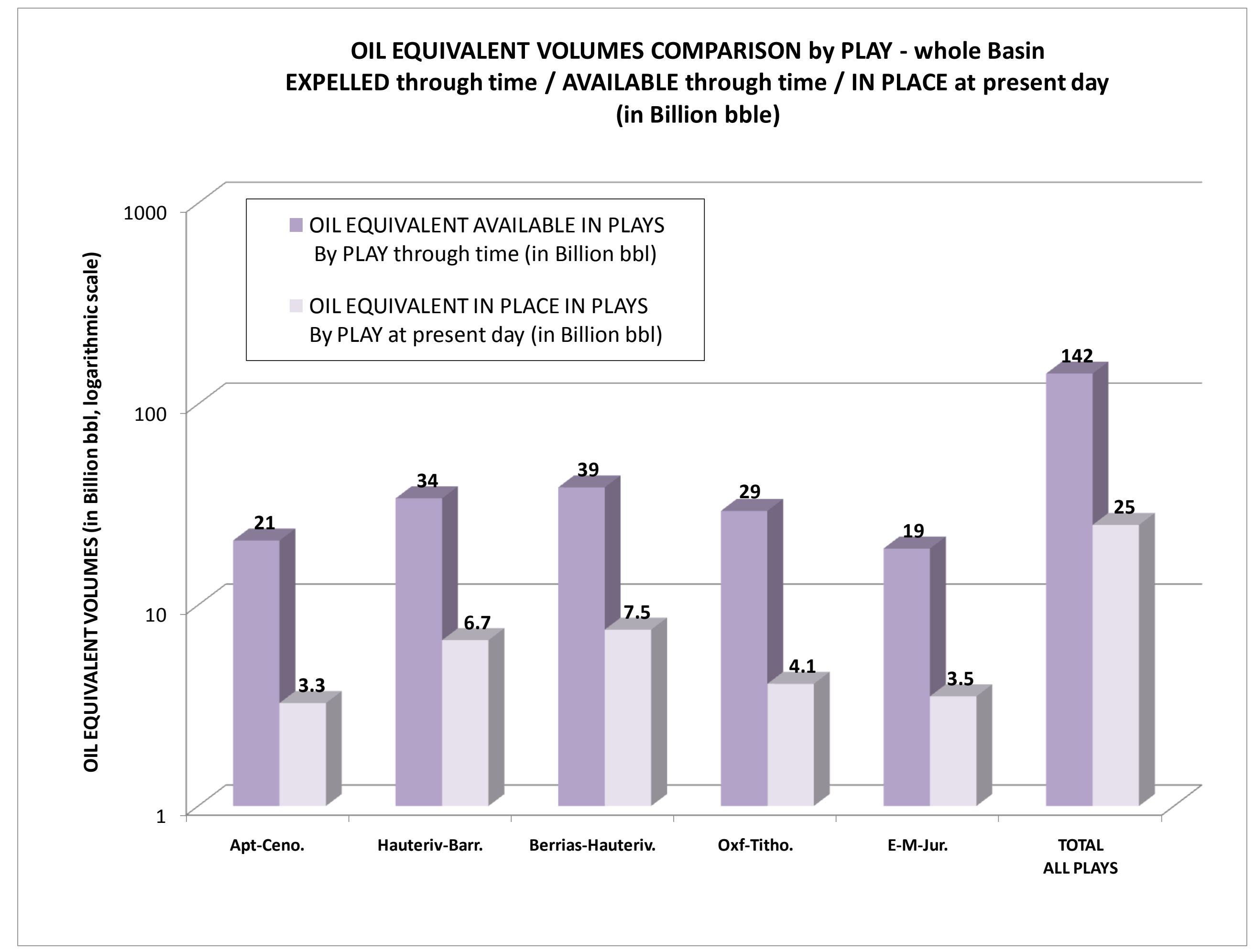


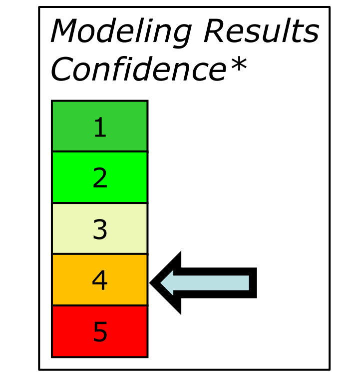




By PLAY

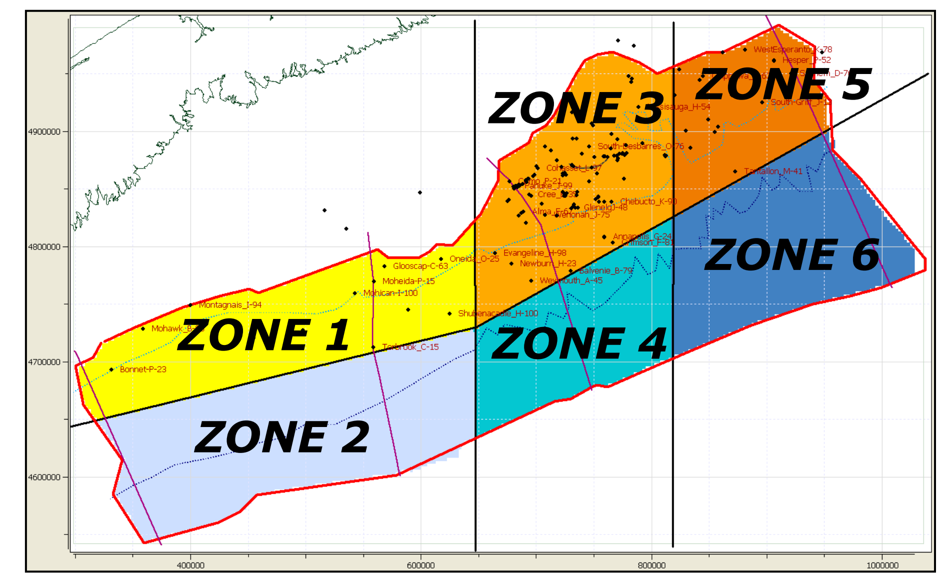






*Except for the following result which is only qualitative (5): "AVAILABLE volume in plays".

PLAY
Aptian-Albian-Cenomanian (K112-K94)
Hauterivian-Barremian (K130-K123)
Berriasian-Valanginian-Hauterivian (J150-K130)
Oxfordian-Tithonian (J63-J150)
Early-Middle-Jurassic (J200-J163)



Expelled / Available / In Place hydrocarbon volumes

Expelled volumes correspond to the total amount of hydrocarbon (oil + gas) expelled ***through geological times*** by all existing source rocks in sub-zones. Note that expelled volumes depend on kerogen types, maturity levels (secondary cracking generates lighter and more mobile hydrocarbons), petrophysical properties of source rock layers.

Available volumes (or Charge Volume) correspond to the total amount of expelled hydrocarbon that migrated ***through geological times inside the play system*** (are not taken into account: amount of hydrocarbons that vertically migrated through faults and never penetrated a reservoir layer, amount of hydrocarbons remaining in source rocks or diluted in carrier beds/shale). Available volumes are the maximum volumes that might be trapped in plays.

In Place volumes correspond to the amount of hydrocarbons present in traps of the plays ***at present day*** (in porous volumes of closed structures).

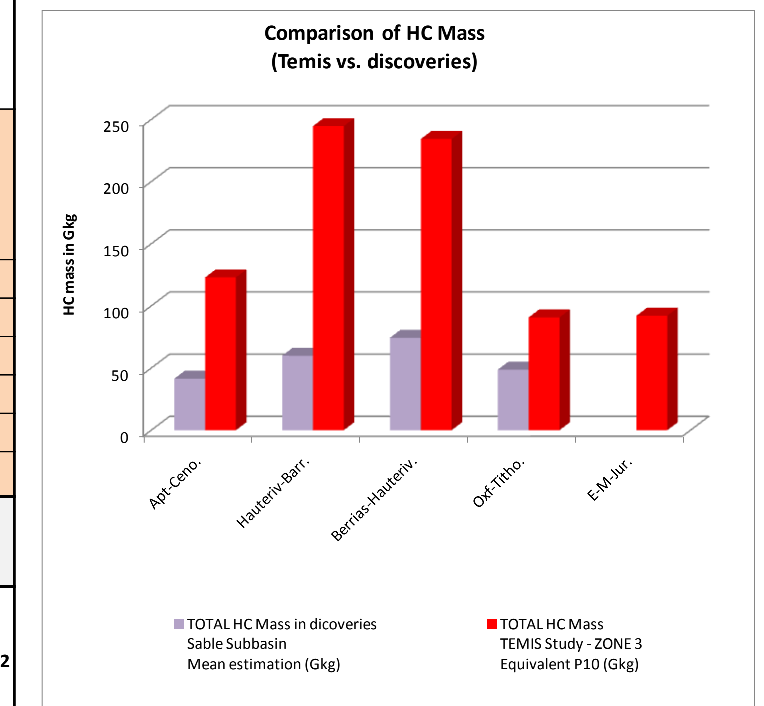
About 2-3% of "expelled hydrocarbons" through geological times are "in place" at present day. This ratio corresponds to the "migration efficiency".
About 10-20% of "available (charged) hydrocarbons" through geological times are "in place" at present day.
The difference between oil and gas ratios (apparent better migration of the gas) is mainly due to secondary cracking between expulsion time and present day (secondary cracking in traps and along migration pathways).

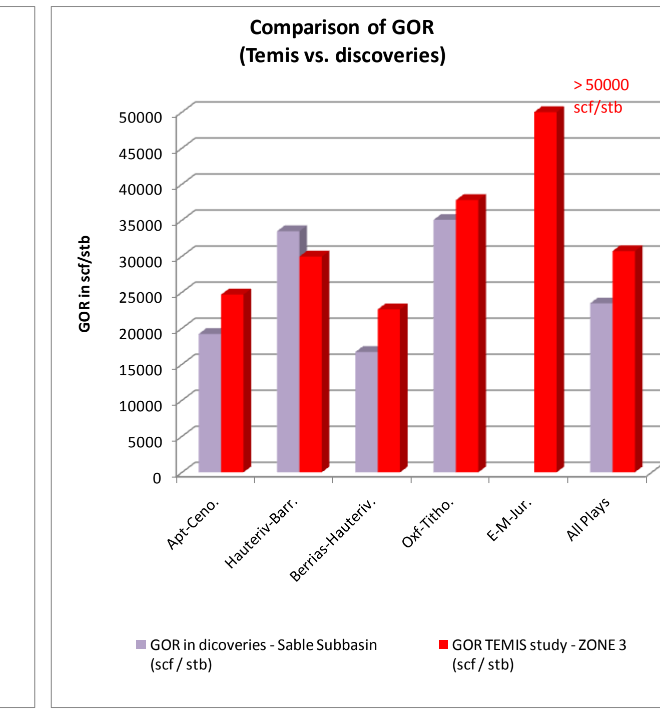
NOTE: Hydrocarbons can migrate from a zone to another one (lateral migration inside reservoir layers). This phenomenon partly explains higher ratios observed in Zone 1: maturity and expulsion are low in Zone 1, but hydrocarbons migrate from zones 2 and 4 into Zone 1.

PLAY SYSTEMS (ZONE 3)	HC in Place in Zone 3 (All Structures, All SR) Equivalent P10 – TEMIS 3D® model – This Study (2011): TOTAL HC mass (Gkg)	TOTAL GAS volume in surface (Tcf)	TOTAL OIL volume in surface (Mbbl)	Estimated HC in Place in Discoveries of the Sable Subbasin – Canada - Nova Scotia Offshore Petroleum Board Technical Summaries of Scotian Shelf Significant and Commercial Discoveries (2000, see p. 11 and 12): TOTAL HC mass (Gkg)	TOTAL GAS volume in surface (Tcf)	TOTAL OIL volume in surface (Mbbl)	GAS in Place Sable Sub-Basin Near-Field Exploration Prospectivity – D. R. Steele (2011): TOTAL GAS volume in surface (Tcf)
Aptien-Albian-Cenomanian (K112-K94)	123	5	210	40	2	82	
Hauterivien-Barremian (K130-K123)	245	11	360	57	3	76	
Berriasien-Valanginien-Hauterivien (J150-K130)	234	10	430	72	3	164	
Oxfordian-Tithonian (J63-J150)	91	4	110	46	2	60	
Early-Middle-Jurassic (J200-J163)	92	5	20				
TOTAL	**785**	**35**	**1130**	**215**	**9**	**381**	**16**
			Ratio PREVIOUS / TEMIS results	27%	26%	34%	46%

	Comment
HC in Place in Zone 3 – TEMIS 3D (This Study)	**Basin modeling approach.** **Volume "IN PLACE".** **"Default" hypothesis (unrisked).** **Study area: 24768 km²** **Medium resolution study (at "plays" or "basin" scale).** The study area is wide and partly unexplored (basinward and deep plays). All closed structure (4 ways traps) are considered, even subtle ones (in term of closure height, reservoir thickness). The study is rather optimistic in term of source rocks and plays (5 SRs and 5 potential reservoirs layers). "Real reservoir" can be scattered in the play interval, non economic and/or non significant (in production tests).
Estimated HC in Place in Discoveries of the Sable Subbasin	**Structural, petrophysical, and statistical approach.** **Volume "IN PLACE".** **"Mean value " hypothesis (unrisked?).** **Approximate study area: < 10 000 km²** **High resolution study (at "prospects" scale)** ***Note:*** *Hydrocarbon distribution between the 5 plays defined in TEMIS is empirical, defined on the basis of partial data.* The Sable Sub-basin is smaller than Zone 3; the basinal part of Zone 3 is not included in the Sable Sub-basin. Only significant or commercial fields are considered. Only producing intervals are considered. No discoveries in the Early-Middle Jurassic. The 5 plays defined in TEMIS have not been recognized by all the wells.
GAS in Place Sable Sub-Basin Near-Field Exploration Prospectivity	**Statistical approach.** **Volume "IN PLACE".** **Approximate study area: < 20 000 km²** **Medium resolution study (at "plays" or "basin" scale)** The study zone is smaller than Zone 3 (Sable Sub-basin and surrounding areas). Albian-Cenomanian Reservoir not included in the calculation.

Comparison Zone 3 / Sable Subbasin

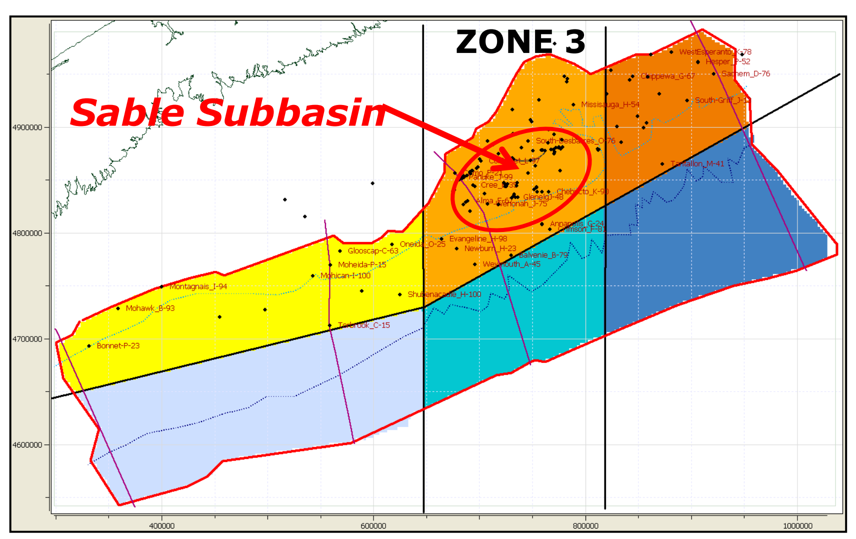




NOTE:

Total HC mass in previous studies is calculated with surface conditions:
d_{oil} = 807 kg/m³ d_{gas} = 0.657 kg/m³.

As a consequence:
1 Gkg = 10^9 kg = 1 million Ton HC ~ 7.8 Mbble



Comparison with previous hydrocarbon volume estimations

Temis® results are consistent with previous hydrocarbon volume estimations from various studies,

At the scale of the **Zone 3 / Sable Sub Basin**, it appears that both distribution between different plays and global GOR are calibrated. Volumes calculated with Temis® are bigger, but the study area is also wider. Temis® results are equivalent to P10 volumes (optimistic), calculated with 5 source rocks and 5 reservoirs.

At the scale of the **whole basin**, the estimation done by A.G. Kidston et al. (2004) is the only one which do not match with Temis® results. This study mainly dedicated to the deepwater part overestimated oil volumes.

Comparison Whole Basin

ZONES	HC in Place - Whole Basin (All Structures, All SR) Equivalent P10 – TEMIS 3D® model – This Study (2011): TOTAL HC mass (Gkg)	TOTAL GAS volume in surface (Tcf)	TOTAL OIL volume in surface (Million bbl)	HC Recoverable Petroleum Resource of the Scotian Shelf – J. A. Wade et al., Geological Survey of Canada, 1989: TOTAL HC mass (Gkg)	TOTAL GAS volume in surface (Tcf)	TOTAL OIL volume in surface (Gbbl)	HC Potential in Place of the Deepwater Slope Offshore Nova Scotia Canada – A. G. Kidston et al., Search and Discovery Article #10063 (AAPG), 2004: TOTAL HC mass (Gkg)	TOTAL GAS volume in surface (Tcf)	TOTAL OIL volume in surface (Gbbl)	Nova Scotia Conventional Offshore Resource Estimates (in Place, Risked) – From CNSOPB, 2008: TOTAL HC mass (Gkg)	TOTAL GAS volume in surface (Tcf)	TOTAL OIL volume in surface (Gbbl)
ZONE 1	584	14	2500									
ZONE 3	785	35	1100									
ZONE 5	708	27	1600									
ZONE 6	621	26	1100									
ZONE 4	411	16	1000									
ZONE 2	187	4	800									
ZONE 1 + 3 + 5 *(platform and upper slope)*	**2077**	**75**	**5200**									
ZONE 2 + 4 + 6 *(lower slope and basin)*	**1218**	**46**	**2900**									
TOTAL / 2	**1648**	**60**	**4100**				**3663**	**83**	**16**			
TOTAL (Whole Basin)	**3295**	**121**	**8100**	**477**	**18**	**1.1**				**2007**	**52.7**	**7.9**
			Ratio PREVIOUS / TEMIS results	14%	15%	13%	222%	138%	398%	61%	44%	97%

	Comment
HC in Place - Whole Basin – TEMIS 3D (This Study)	**Basin modeling approach.** **Volume "IN PLACE".** **"Default" hypothesis (unrisked).** **Study area: 141963 km²** **Medium resolution study (at "plays" or "basin" scale).** The study area is wide and partly unexplored (basinward and deep plays). All closed structure (4 ways traps) are considered, even subtle ones (in term of closure height, reservoir thickness). The study is rather optimistic in term of source rocks and plays (5 SRs and 5 potential reservoirs layers). "Real reservoir" can be scattered in the play interval, non economic and/or non significant (in production tests).
HC Recoverable – J. A. Wade et al., 1989	**Statistical approach.** **Volume "RECOVERABLE".** **"Median value " hypothesis (unrisked?).** **Approximate study area: > 100000 km²** **Medium-Low resolution study (at "basin" scale).** This study area seems comparable to TEMIS study area, even if it mainly focusses on the shelf. Oil volumes seem overestimated in this study. Only "recoverable" volumes are available. "In place" volumes can be up to one order of magnitude higher.
HC Potential in Place of the Deepwater Slope – A. G. Kidston et al., 2004	**Statistical approach.** **Volume "IN PLACE".** **"Mean value" unrisked hypothesis.** **Approximate study area: > 60 000 km²** **Medium-Low resolution study (at "basin" scale).** This study area is wider than Zone 2+4+6. In fact the "deep water slope" described in this paper includes several subzones defined in TEMIS, and could be compared to half of Temis study area. Oil volume (including condensate) seems overestimated in this study. Gas volume (including solution gas) is more realistic.
Nova Scotia Conventional Offshore Resource Estimates – CNSOPB, 2008	**Bibliographic synthesis of previous studies.** **Volume "IN PLACE".** **"Mean value" risked hypothesis.** **Approximate study area: > 150000 km²** **Low resolution study (at "basin" scale)** This study zone is wider than Temis® study area (Orpheus Basin and George Bank included). However both studies can be compared. This study partly takes into account A.G. Kidston et al.'s results (2004). Only "risked" volumes are available for the whole basin. "Unrisked" volumes can be several time higher.