

# **PS Estimating the Ultimate Expellable Potential of Source Rocks: Defining “World Class” for Aquatic Organofacies with Examples from the Arabian, West Siberian, Bohai, and Williston Basins\***

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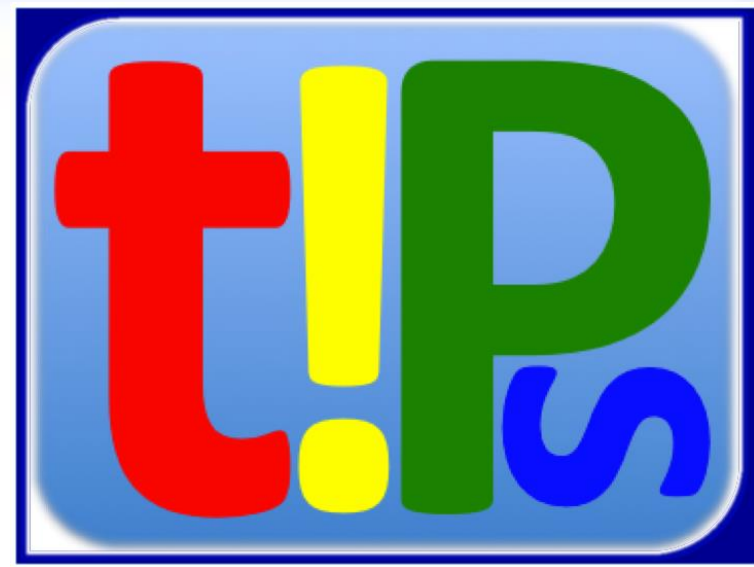
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## **Abstract**

An important step in the evaluation of a play or prospect is to consider the potential supply of petroleum charge, which is ultimately constrained by masses and volumes supplied by the source bed. The two factors limiting the mass of petroleum expelled from the organic matter in the source bed are: (1) its initial expulsion potential, and (2) the cumulative fraction of potential that has been expelled up to its maximum state of maturation. To evaluate the initial expulsion potential, we introduce a workflow to estimate the Ultimate Expellable Potential (UEP), which represents the cumulative mass of oil and gas that can be expelled upon complete maturation of the source rock. For use in resource estimation, these masses can be converted to surface volumes of oil and gas per unit area (mmstb/km<sup>2</sup> and bscf/km<sup>2</sup> or mmboe/km<sup>2</sup>, respectively). UEP can be mapped across the depositional extent of the source bed, just as a reservoir depositional system can be mapped.

We show examples of UEP mapping based on available public data. Three of the example source rocks are aquatic Organofacies that have charged major conventional petroleum systems: the marine Organofacies A Middle to Upper Jurassic of the Arabian Basin, Saudi Arabia; the marine Organofacies A/B Volgian Bazhenov Formation of the West Siberian Basin, Russia; and the lacustrine Organofacies C Eocene-Oligocene Shahejie Formation of the Bohai Basin, China. We also include an unconventional system: the marine Organofacies B latest Devonian-earliest Mississippian Bakken Formation of North Dakota, USA. The UEPs of the studied source rocks in the Arabian Basin and West Siberian Basin define “World Class” in marine source rocks since these basins are ranked number one and number two in the world by oil endowment. Until more data is available on other lacustrine basins, we offer the UEP of the studied Bohai Basin source rock as an example. In contrast, the UEP of the Bakken Formation source rocks (combined Upper and Lower Members) is relatively small despite its “World Class” unconventional oil endowment. The Bakken's effectiveness, despite its relatively low UEP, reflects the negligible migration losses involved in charging the Middle reservoir member. This illustrates that the often-touted term “World Class” can be rather meaningless. It needs to be considered in context given the task in hand: the greater the (vertical) migration losses incurred in charging reservoirs, the higher the UEP will need to be to overcome them.

# Estimating the Ultimate Expellable Potential of Source Rocks: defining “World Class” for aquatic Organofacies with examples from the Arabian, West Siberian, Bohai and Williston Basins



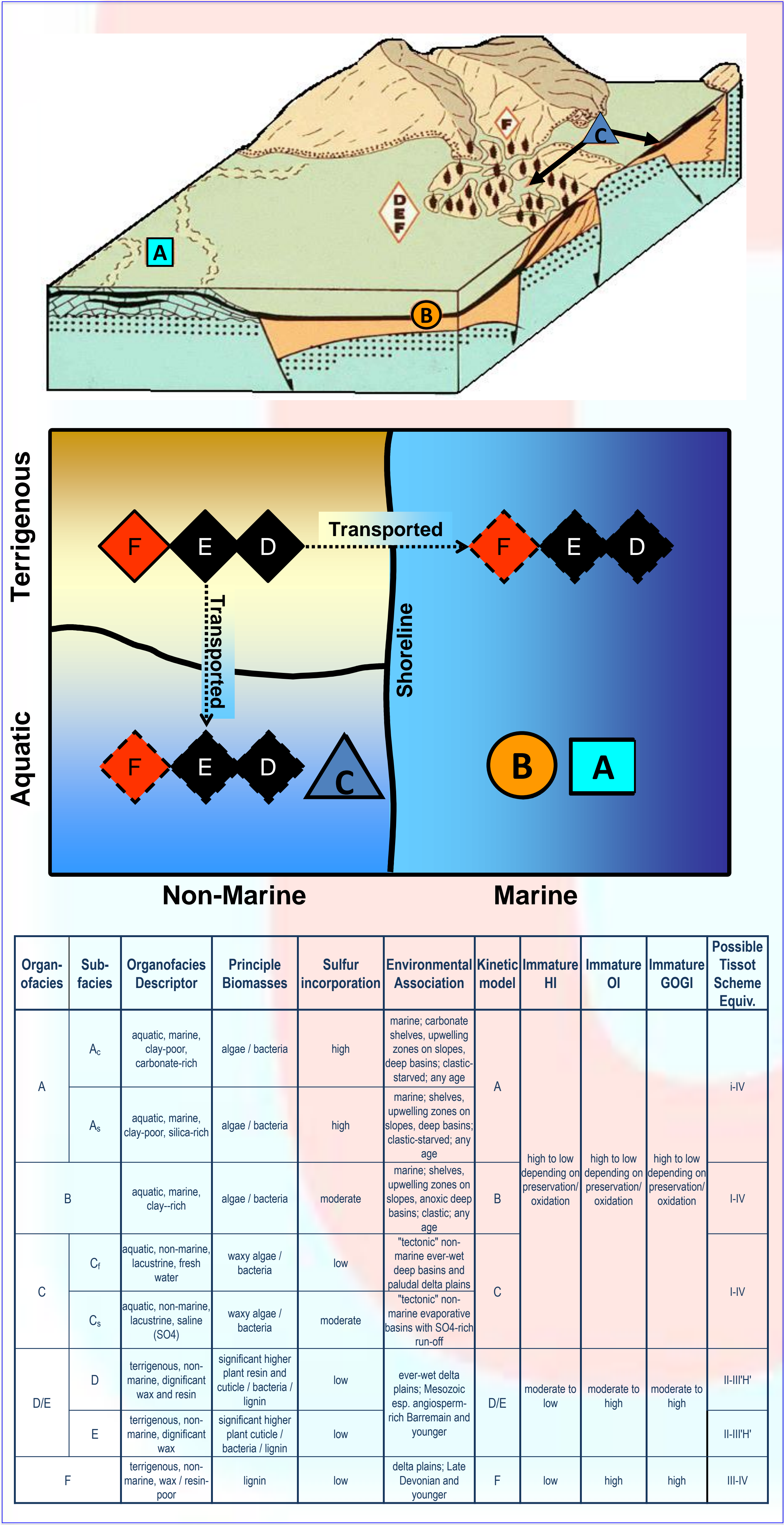
Elizabeth Roller and Andrew Pepper

This is Petroleum Systems LLC, Houston, TX, USA

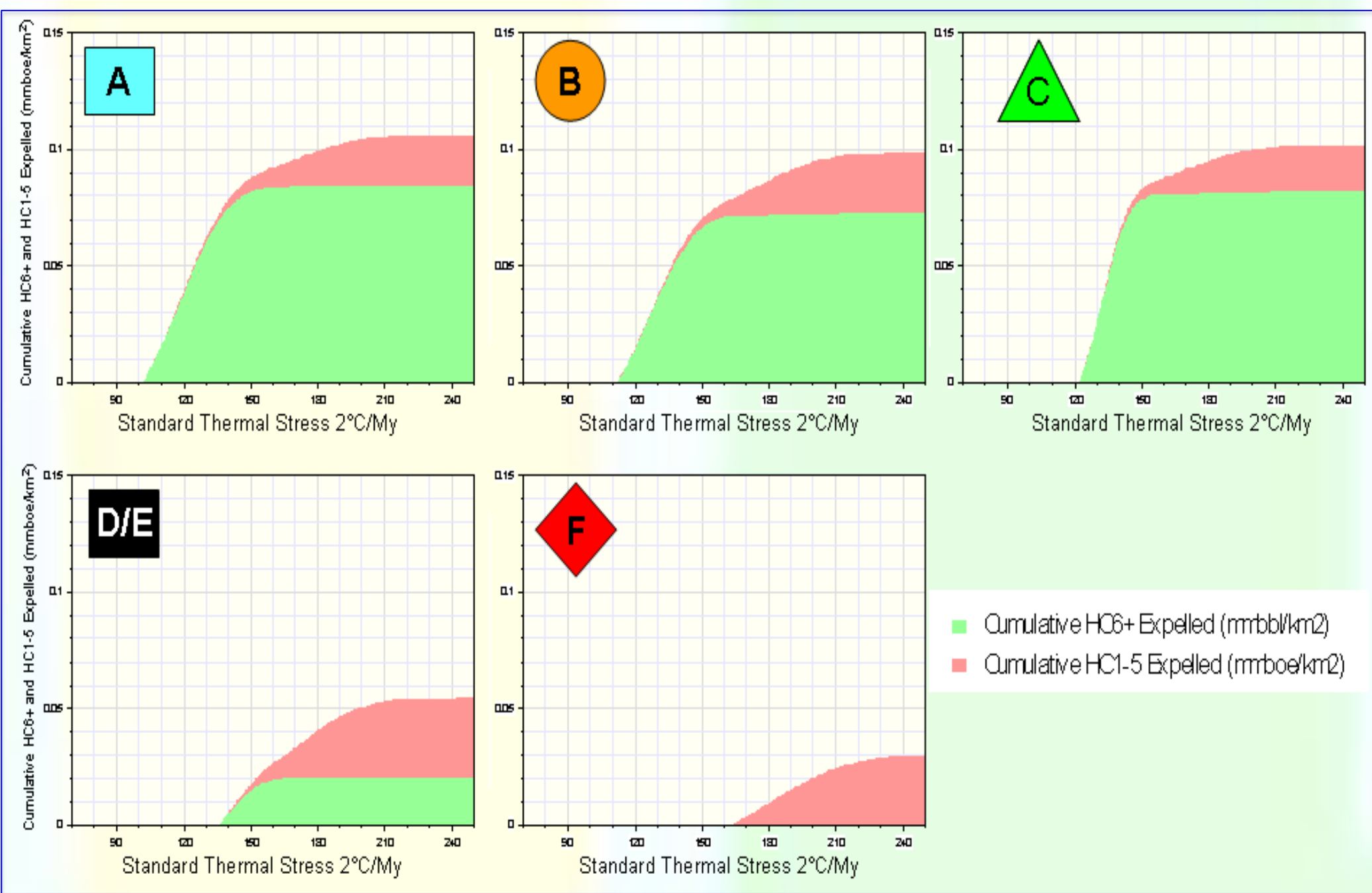
American Association of Petroleum Geologists 2017 ACE, Houston, TX, USA, April 3<sup>rd</sup> 2017

How we define Organic Matter (OM) type:  
the Organofacies Scheme

How expelled oil & gas yield profiles (mmboe/km<sup>2</sup>, normalized per m per % Corg)  
vary with Organofacies and HI. *HI and ‘type’ are independent*

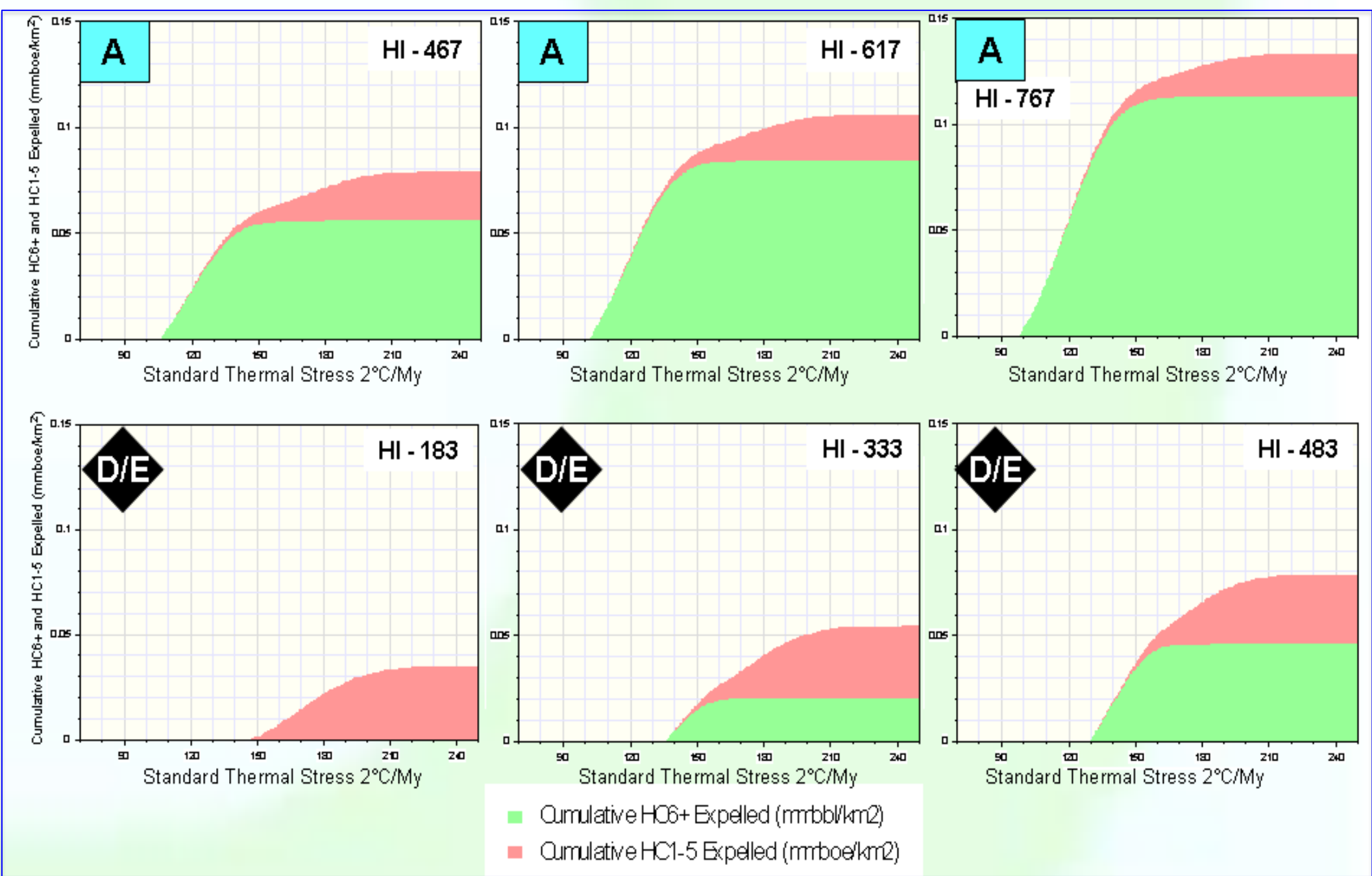


Cumulative Expelled: Of\_A through Of\_F with 'default' HI



Using KinEx calculator (Zetaware), we calculate cumulative expelled volumes as a function of Organofacies and initial properties: C<sub>org</sub>, Hydrogen Index and also GOGI (Gas/Oil Generation Index), and TI (Transformation Index)

Cumulative Expelled: Of\_A & Of\_D/E 'default' +/- 150 HI



## How to use UEP in a Petroleum Systems Analysis or Resource Assessment

**Ultimate Expellable Potential (UEP) is a volumetric integral, per unit area, that reflects “adequacy” of a source bed**

- Takes into account its vertical stratigraphic heterogeneity and lateral stratigraphic variability

**Like other regional elements, UEP varies across a basin or play**

- Lateral variability tends to increase from aquatic marine (A, B) to terrestrial (non-marine) environments with aquatic (C) OM, and finally to environments with terrigenous OM input (D, E, F)
- Mixed OM settings (B+D/E/F, C+DEF) are highly variable

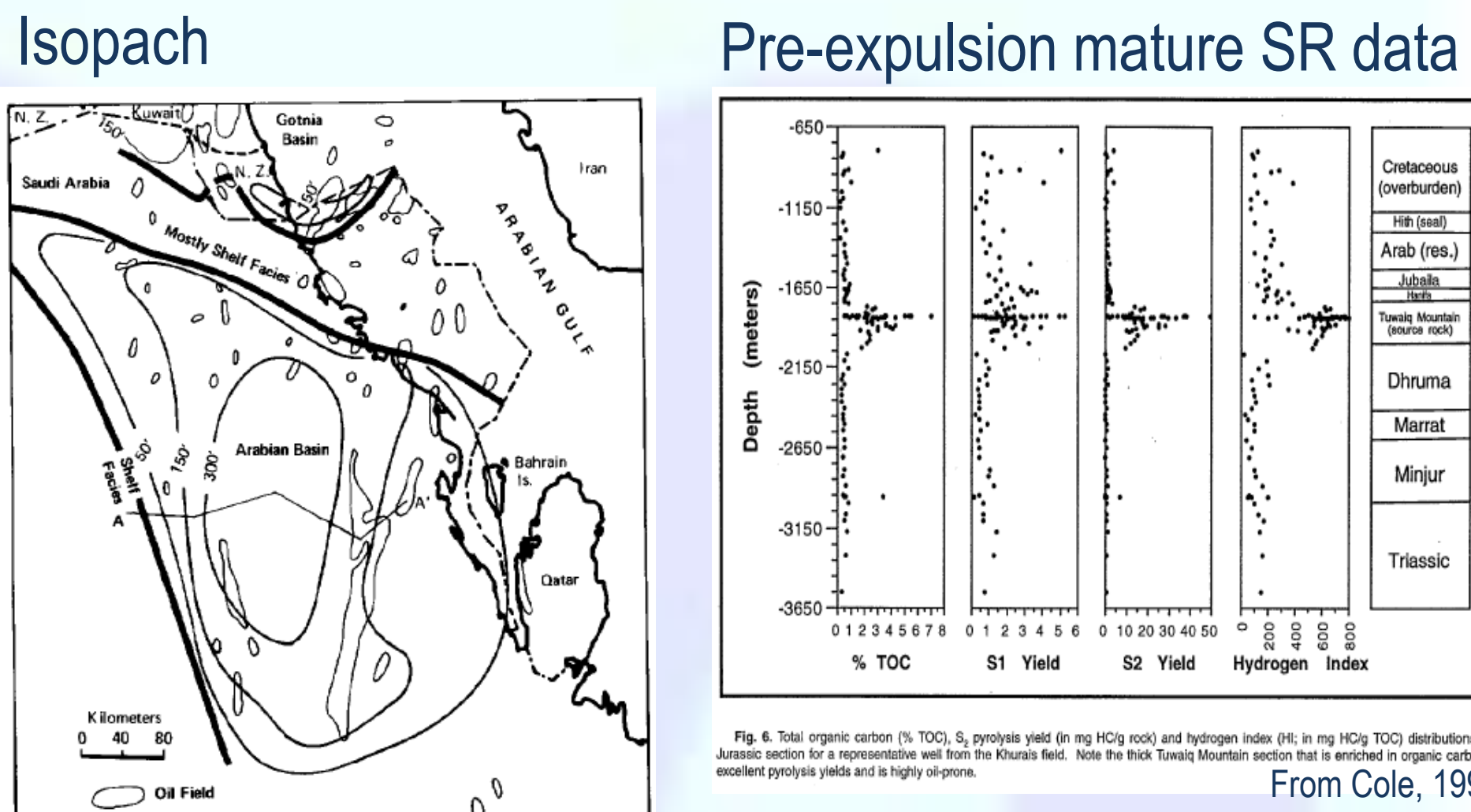
**Here we describe UEP in map form and invite a comparative approach: what does “World Class” UEP really look like?**

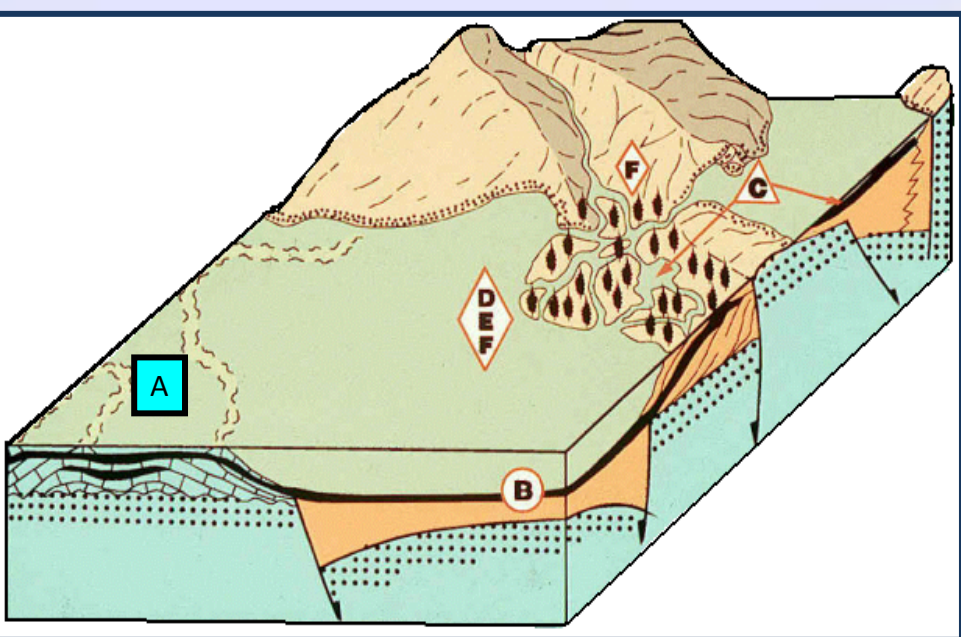
- Per unit area yields of expelled oil (PC05+), gas (PC01-05) and total are expressed UEO, UEG, and UEP, respectively
- Expressed in mmboe/km<sup>2</sup> for integration across prospect fetch area

**“Adequacy” then depends on context:**

- A modest UEP within closely-coupled reservoir/source bed system with few migration losses and a large focused fetch - e.g. Eagleford-Woodbine, East Texas Basin - may be just as adequate as:
- High UEP in a widely separated reservoir/source system requiring much vertical migration and with more limited fetch areas - e.g. Jurassic-Miocene, GoM minibasins

## Types of info needed to calculate & map UEP





# Tuwaiq Mountain Fm, Arabian Basin: marine aquatic Organofacies A<sub>c</sub>

**Age:** late Callovian-early Oxfordian paleothermal maximum - Acme 161

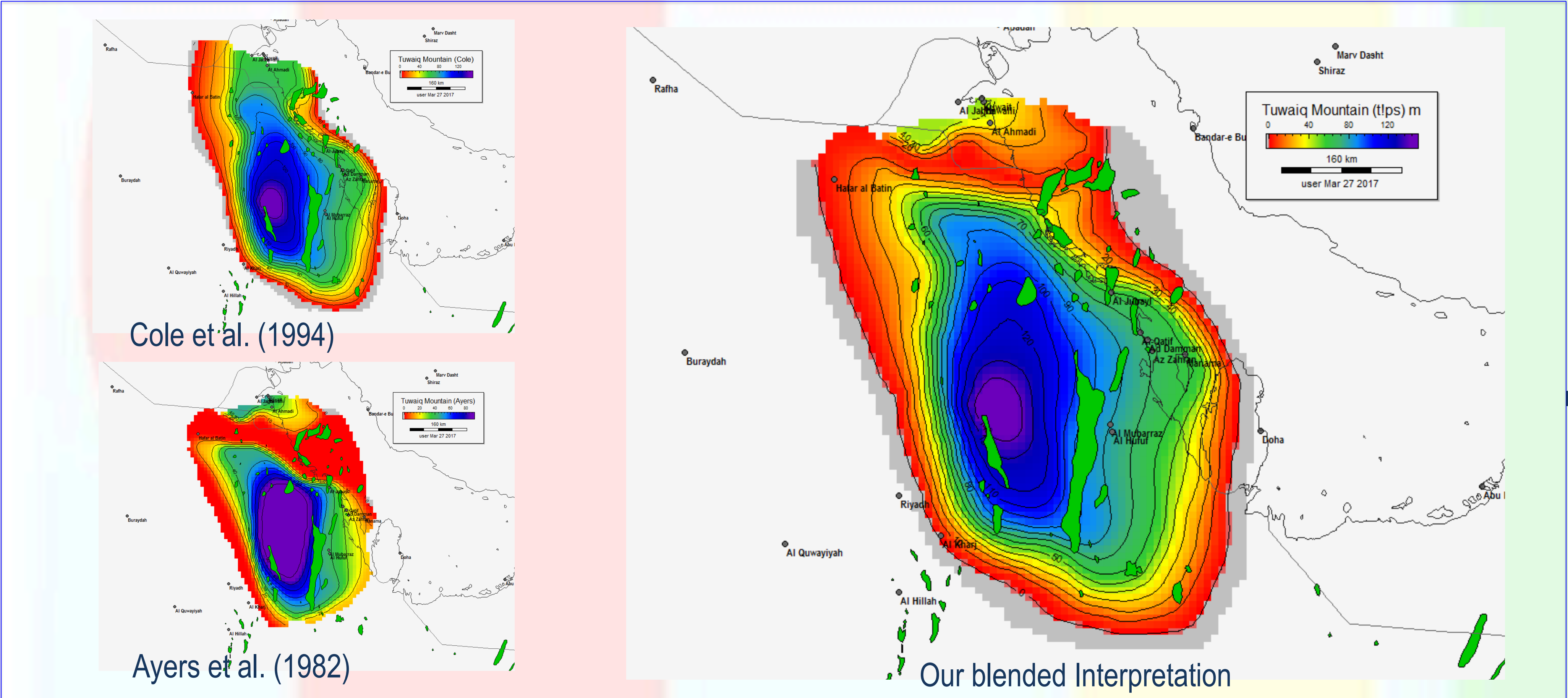
**Lithology:** laminated clay-poor calcareous mudstones (A<sub>c</sub>)

**EOD:** shallow intra-shelf basin confined by coeval Tuwaiq Mountain carbonate platform growth

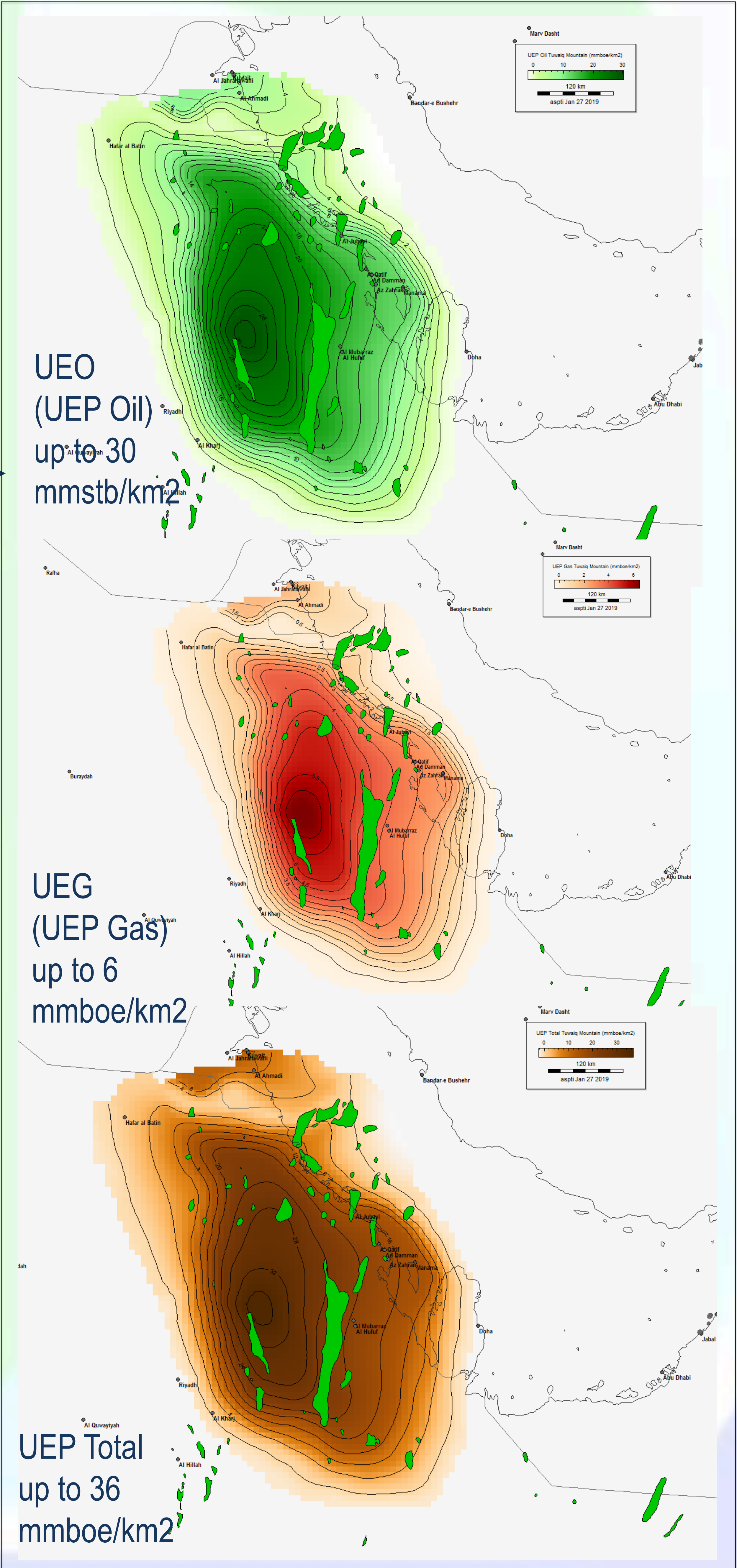
**Context:** main source interval for the basin with the worlds largest conventional oil endowment and field (Ghawar)

## Map Components

Isopach of dark mudstone > 1% C<sub>org</sub>



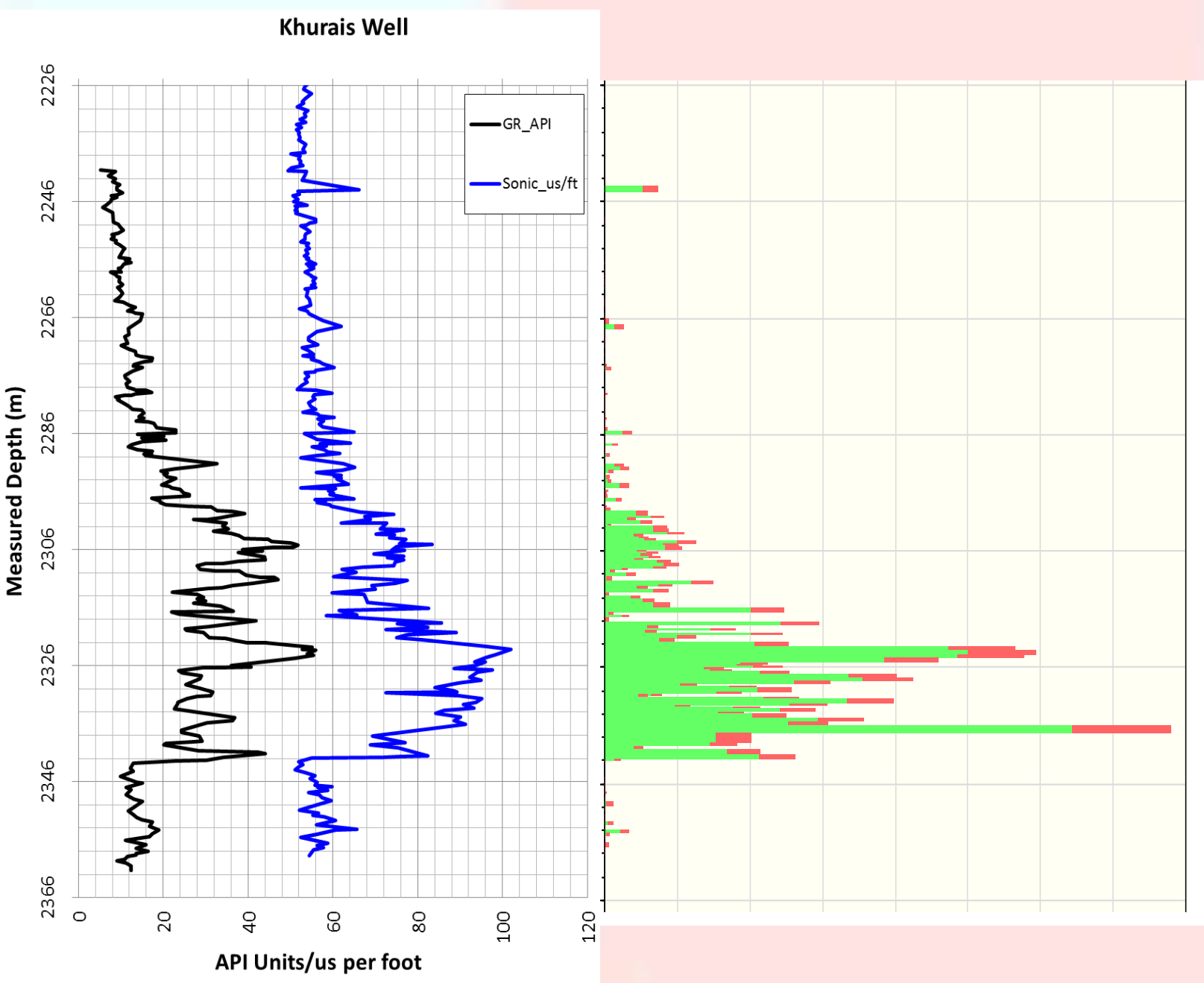
## UEP Map Results



UEP per m multiplied by isopach produces the UEP map

## Establish UEP per m at pre-expulsion well (Khurais area)

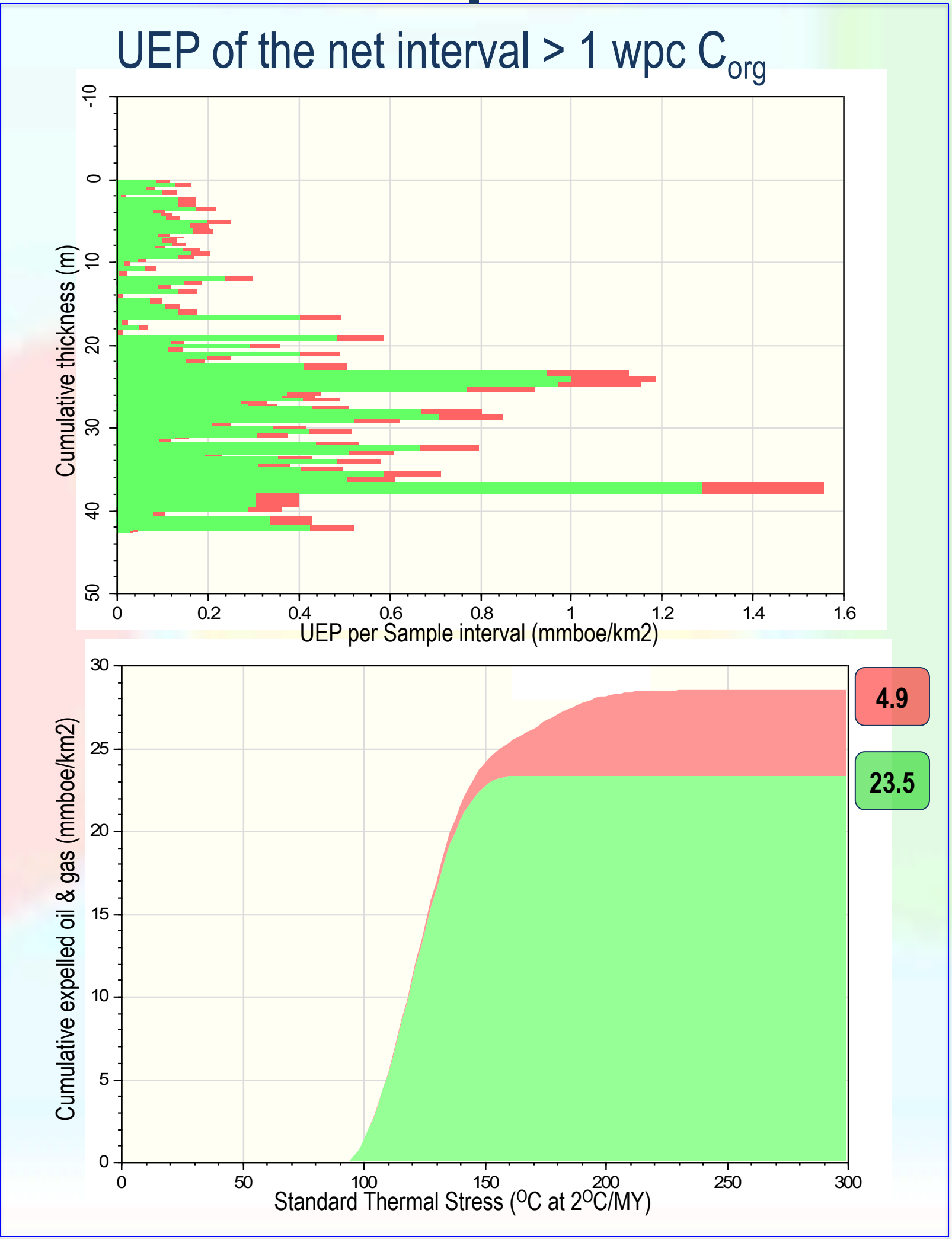
Well screened for C<sub>org</sub> by extrapolation of data using wireline density log.



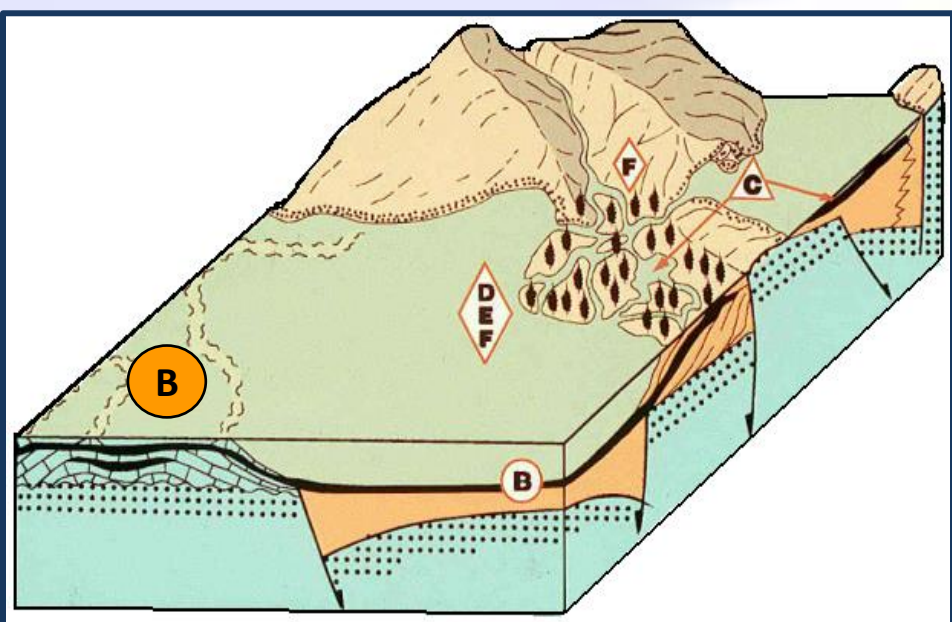
UEP per m calculated for the gross interval shown in the maps above

	Oil	Gas	Total	Thickness
mmstb/km2	23.4646	4.9604	28.425	116.3
mmstb/km2/m	0.202	0.043	0.244	

UEP re-calculated for each later in the net interval with C<sub>org</sub> > 1 wpc



HI derived from Immature HI vs. Corg relationship from data in by Cole et al (1994). UEP calculated for each layer to screen the gross Callovian-Oxfordian well interval (Zetaware's Kinex calculator)



# Bazhenov Fm, W. Siberian Basin: marine aquatic Organofacies A/B:

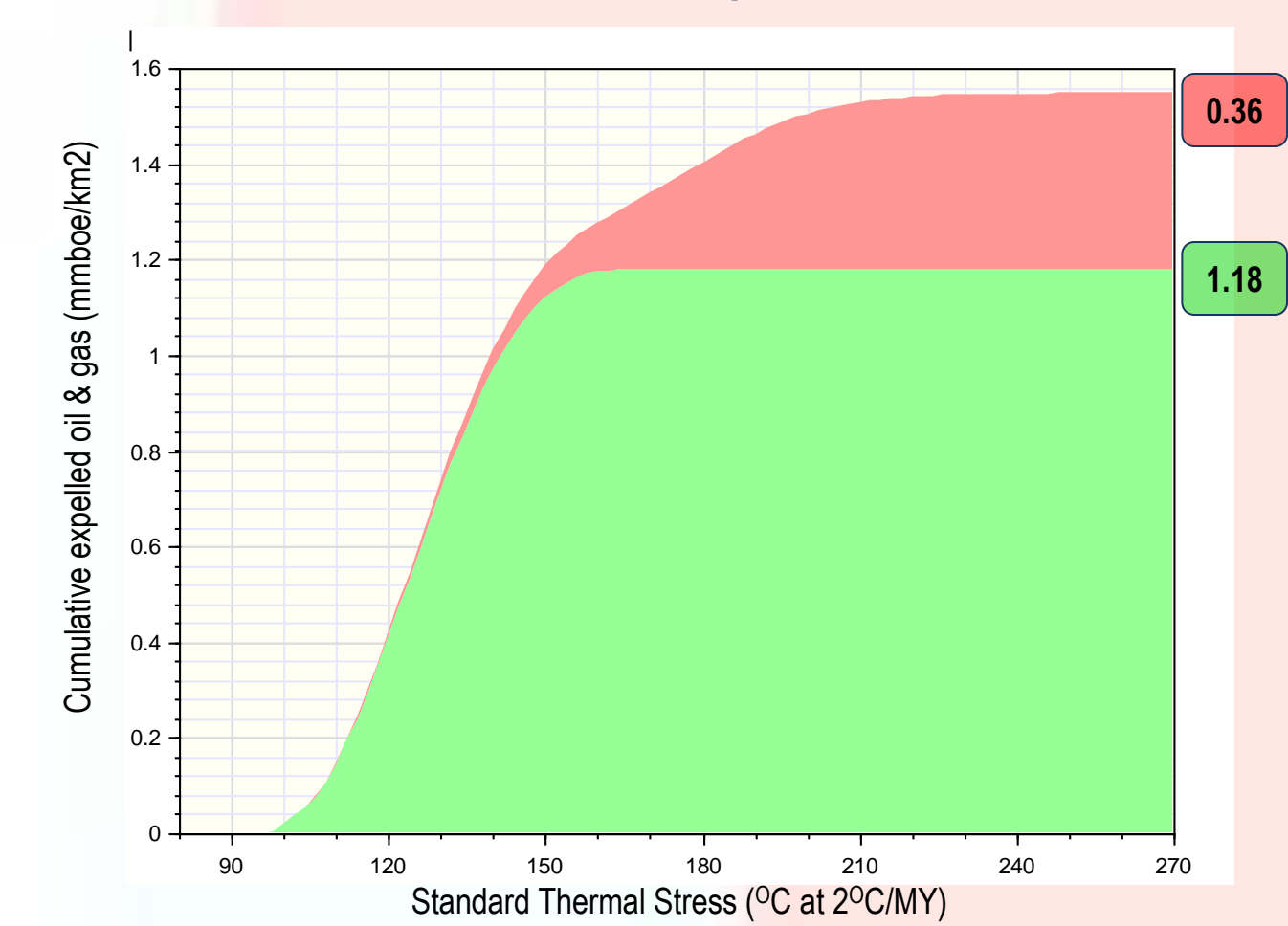


**Age:** Volgian (Tithonian-early Berriasian); global Acmes 144 & 148 combined  
**Lithology:** organic-rich argillaceous-siliceous mudstones interbedded with radiolarites and argillaceous limestones  
**EOD:** silled anoxic basin during marine transgression accompanying an increase in tectonic subsidence  
**Context:** source rock for 80-90% of the oil in a basin with the world's second largest conventional oil-endowment

## Map Components

Map UEP per meter per %C<sub>org</sub>

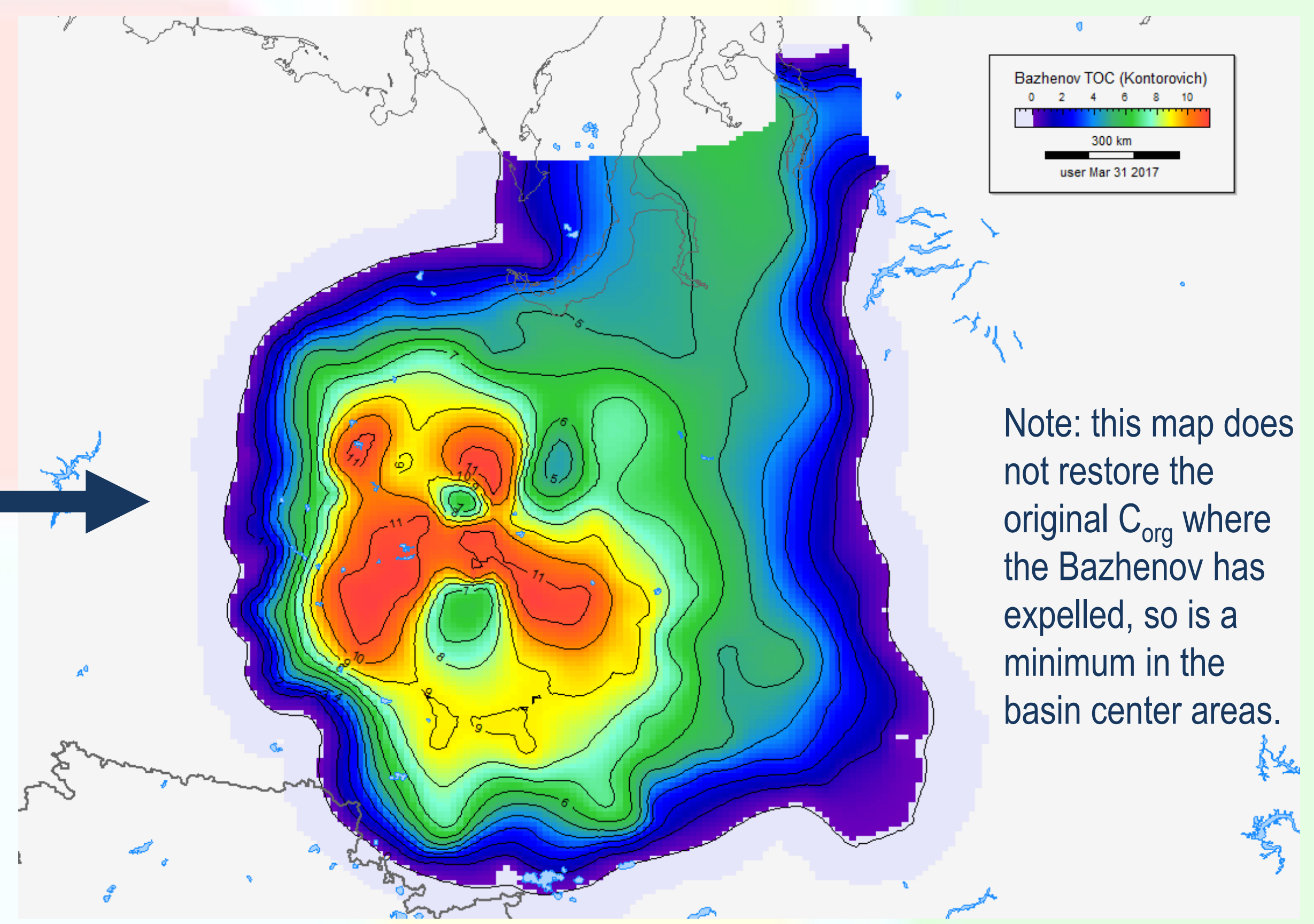
Bazhenov UEP (mmboe/km2/m)



AVG TOC		15.68697674
	mmboe/km2/m	mmboe/km2/m/%TOC
ALL	1.54961	0.09876
OIL	1.1845	0.07551
GAS	0.36511	0.02325

Pre-expulsion maturity SR data from Hegre et al (1998) normalized to UEP per meter per %C<sub>org</sub> allows subsequent expansion using maps of C<sub>org</sub> and thickness which vary widely across the basin: UEP per m per %C is multiplied by C<sub>org</sub>, then by the isopach of anoxic Volgian facies.

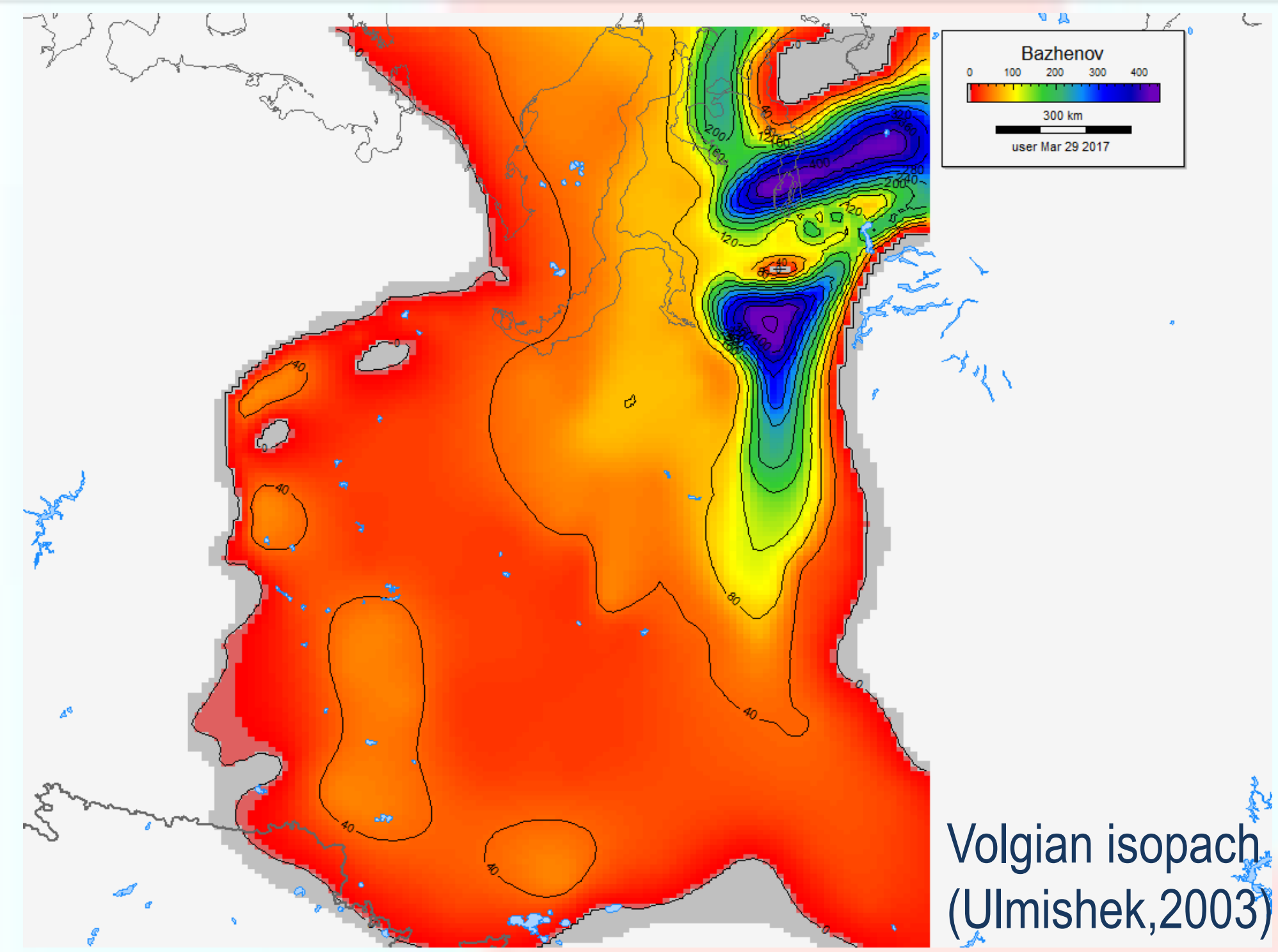
Full thickness of the immature section was not completely sampled, but available data was assumed representative: the data was normalized to a 1m section and then to a per %C<sub>org</sub> basis



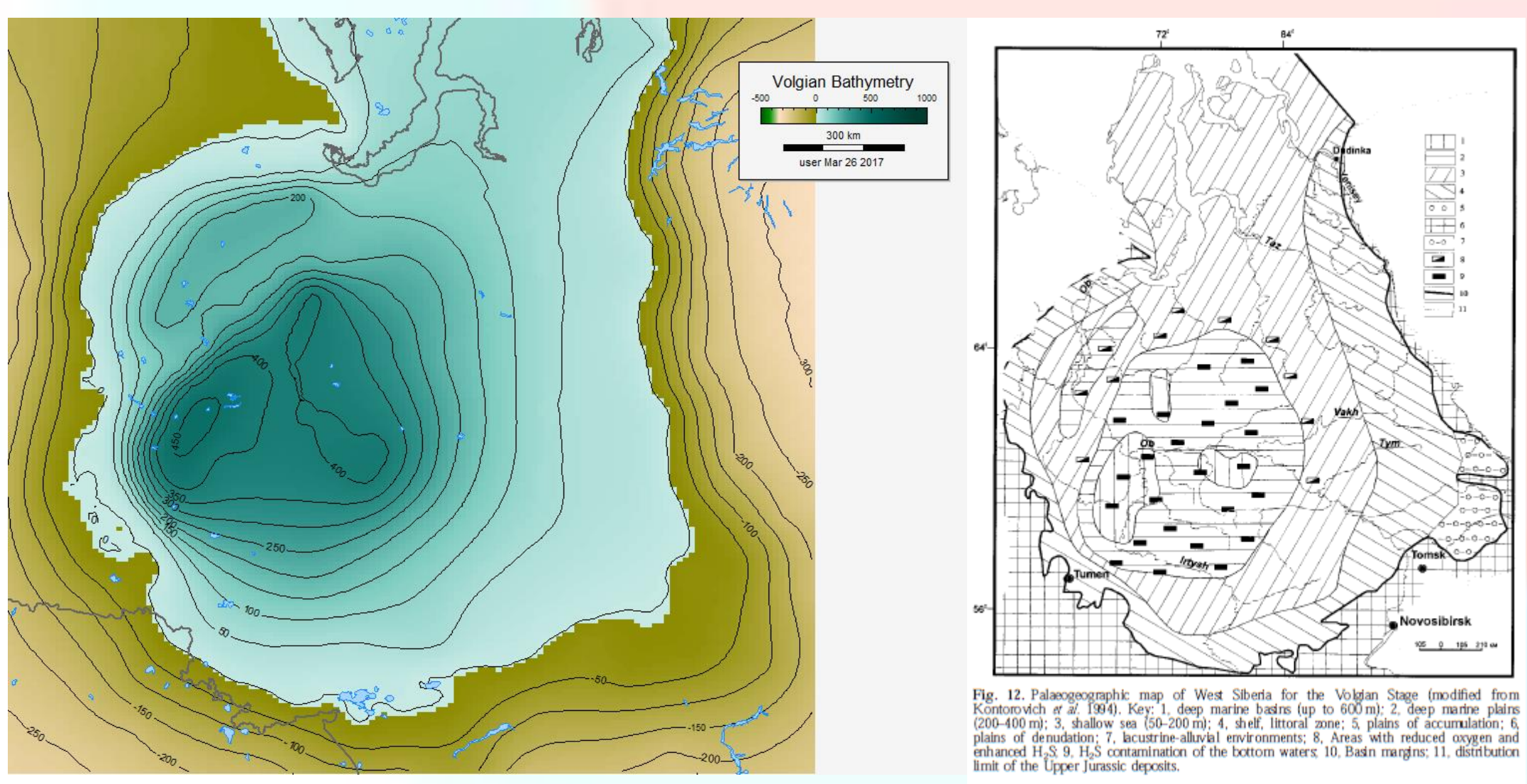
Note: this map does not restore the original C<sub>org</sub> where the Bazhenov has expelled, so is a minimum in the basin center areas.

Bazhenov Corg\_wpc (Kontorovich et al 1997)

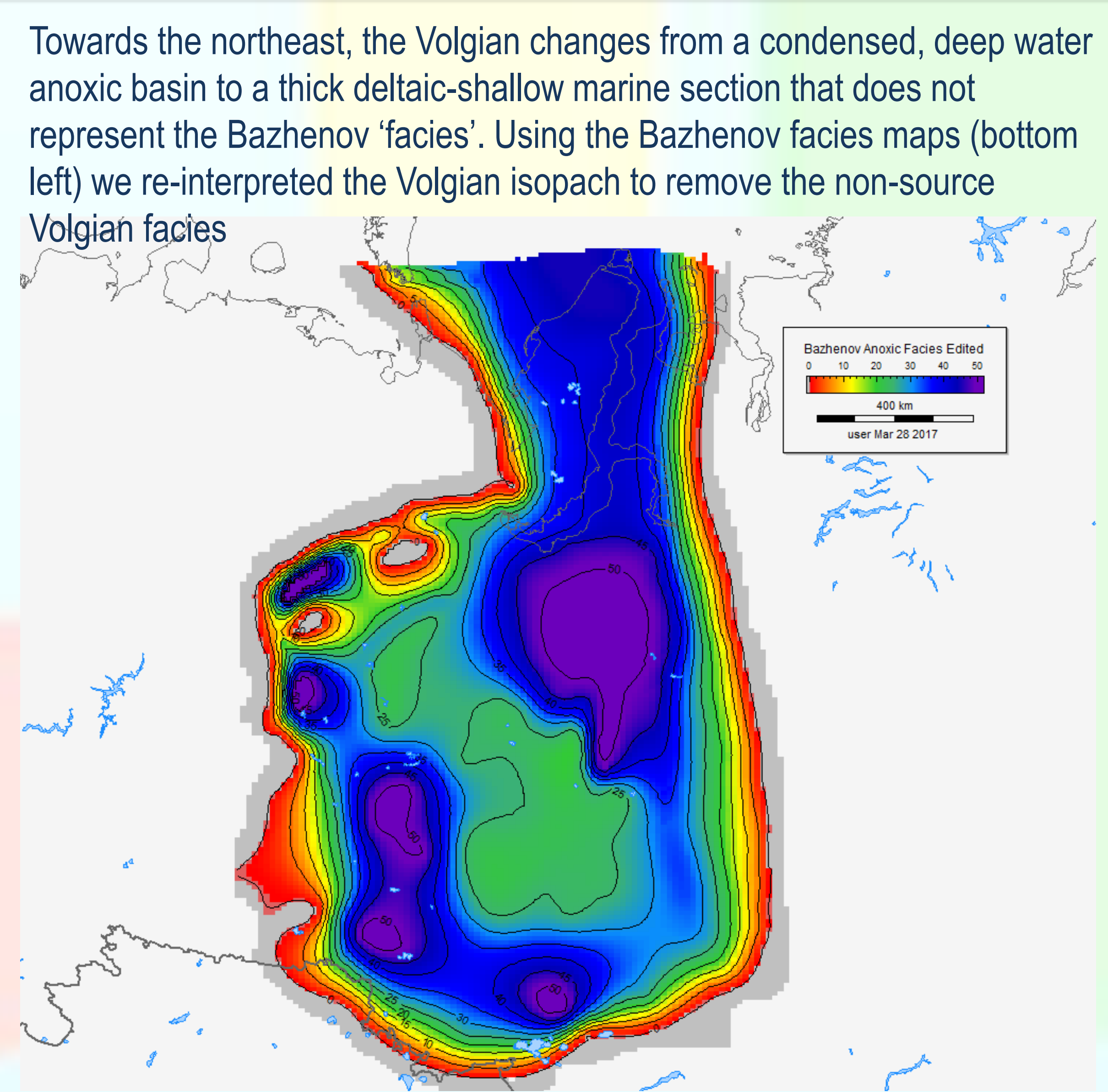
## Map thickness of the anoxic Bazhenov facies within the Volgian



Volgian isopach (Ulmishek, 2003)

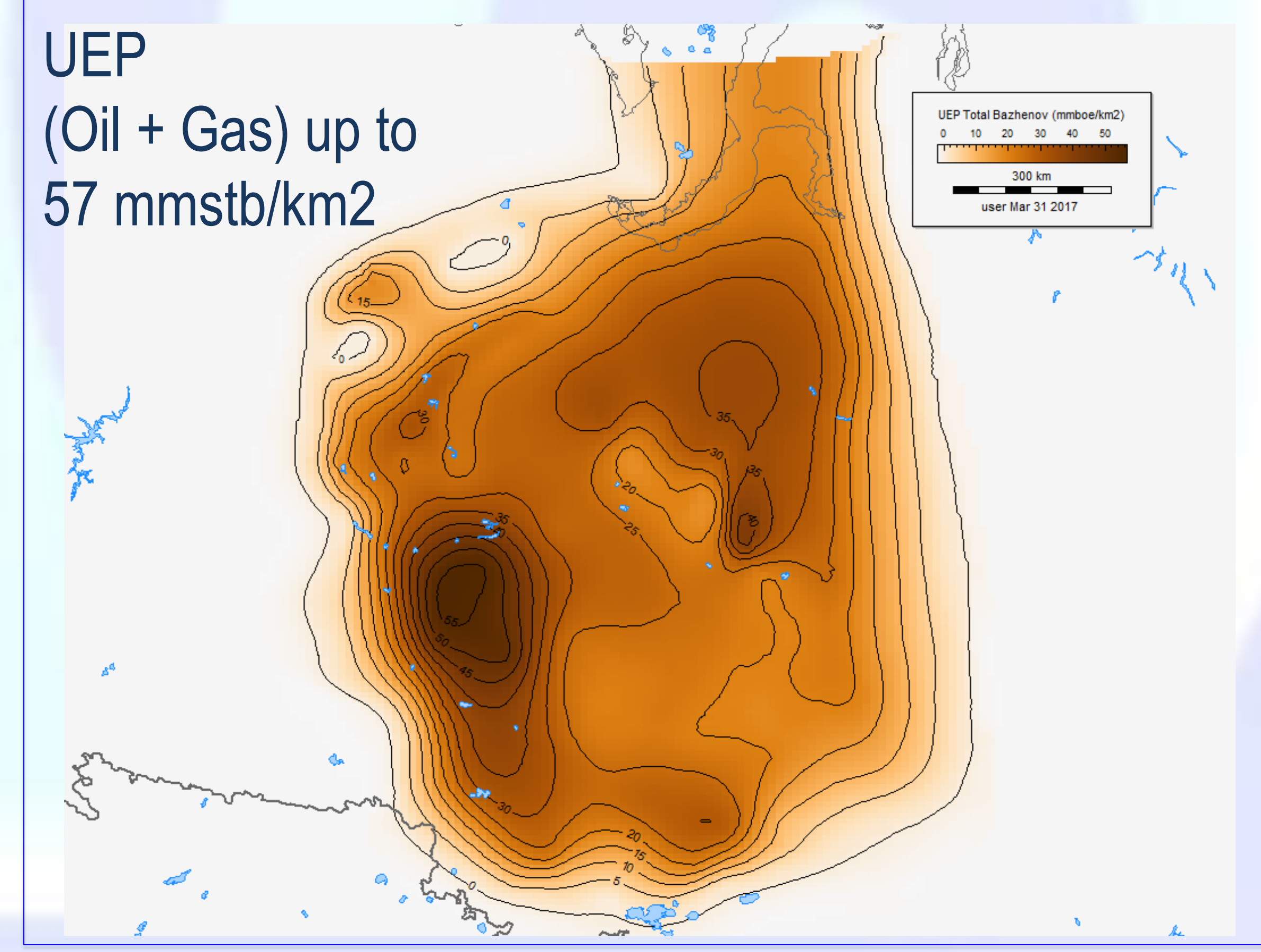
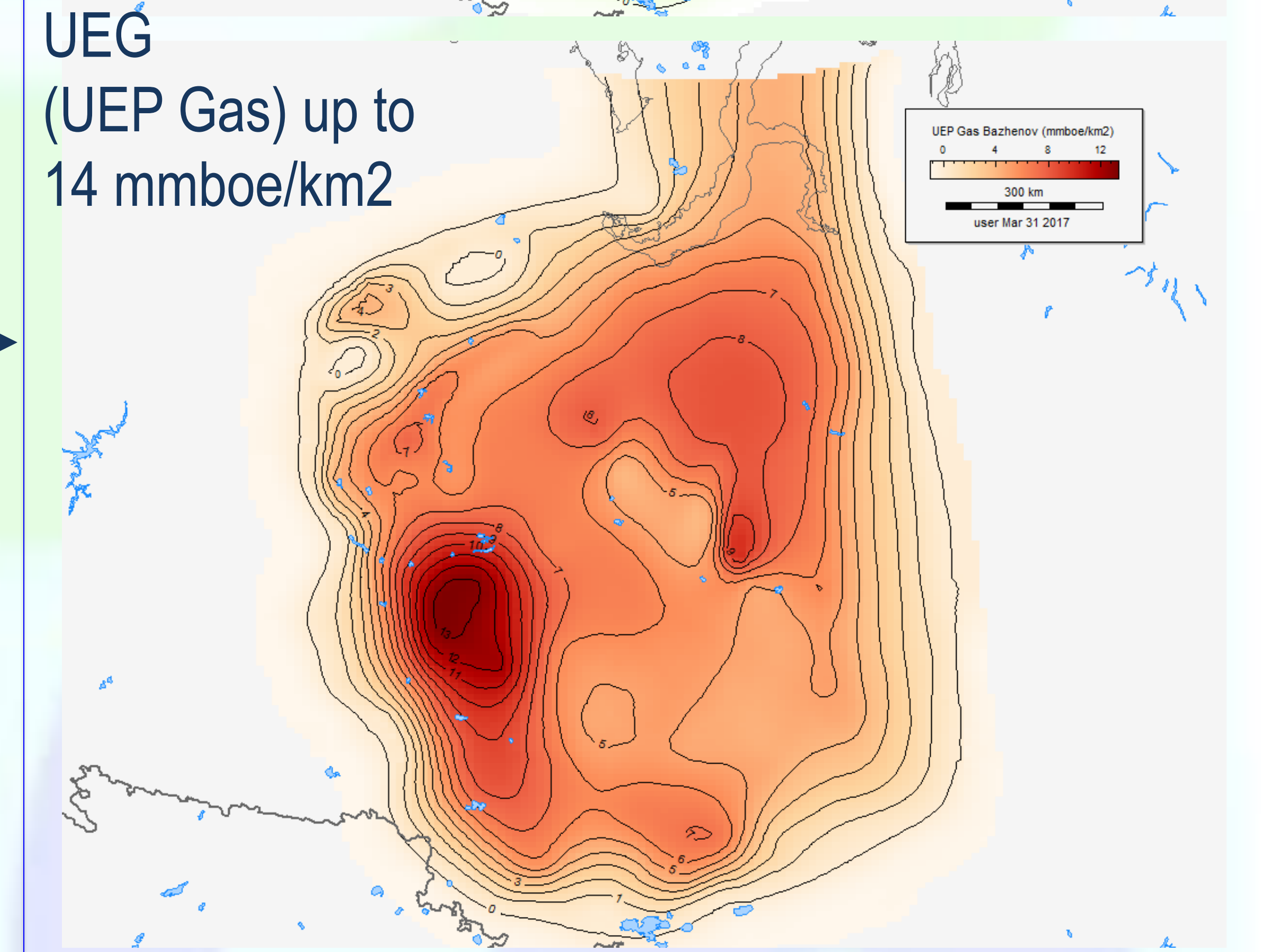
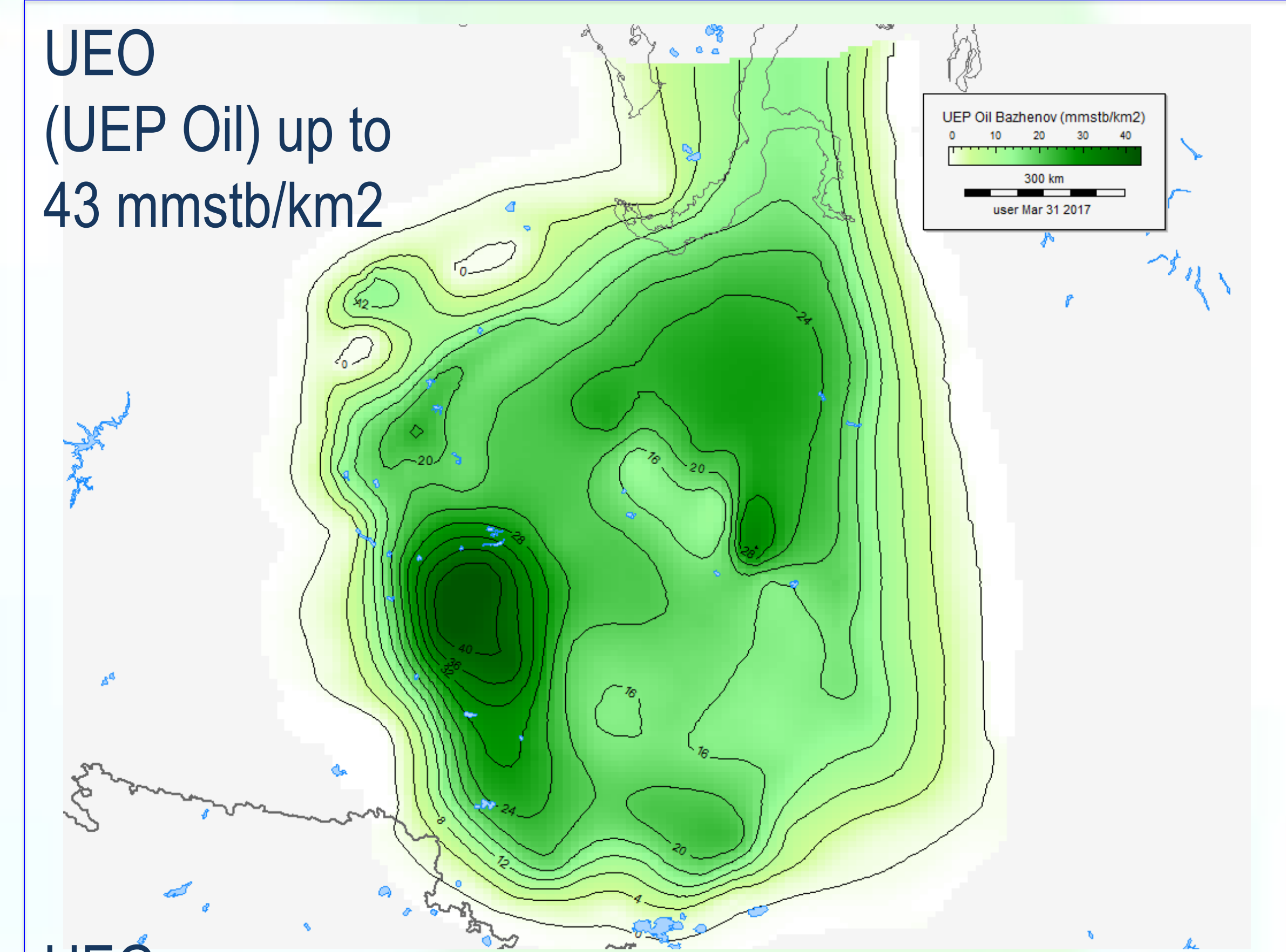


Volgian bathymetry and facies (reduced oxygen and enhanced H<sub>2</sub>S area) maps (Kontorovich et al 1997)



Our Bazhenov facies isopach Interpretation

## UEP Map Results



# Shahejie Fm 3<sup>rd</sup> Mbr, Bohai Basin: lacustrine aquatic Organofacies C<sub>f</sub>



**Age:** Eocene

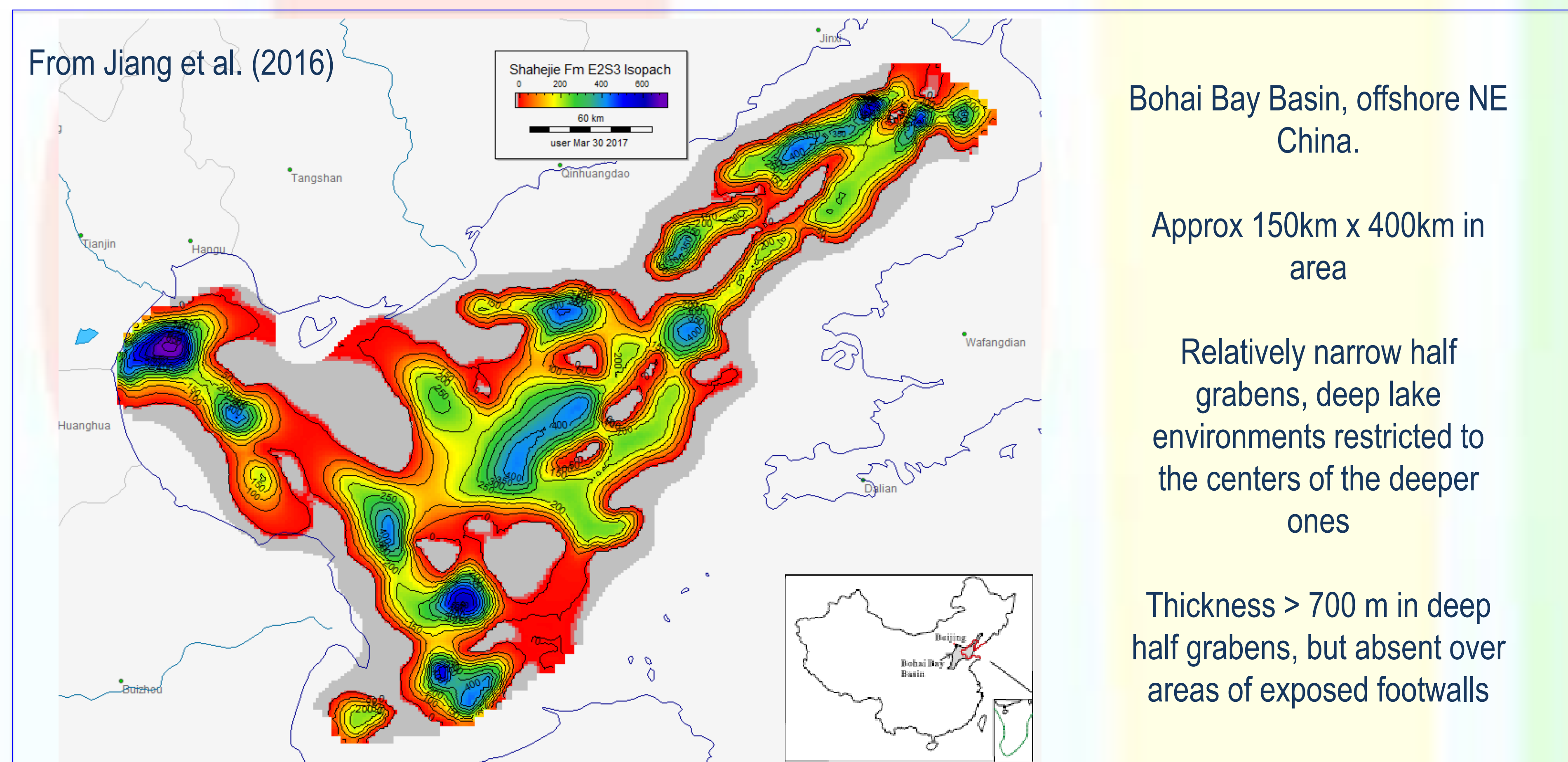
**Lithology:** dark clay-rich mudstone

**EOD:** freshwater lake in warm, humid climate, facies ranging from shallow lake margin to deep lake in half grabens

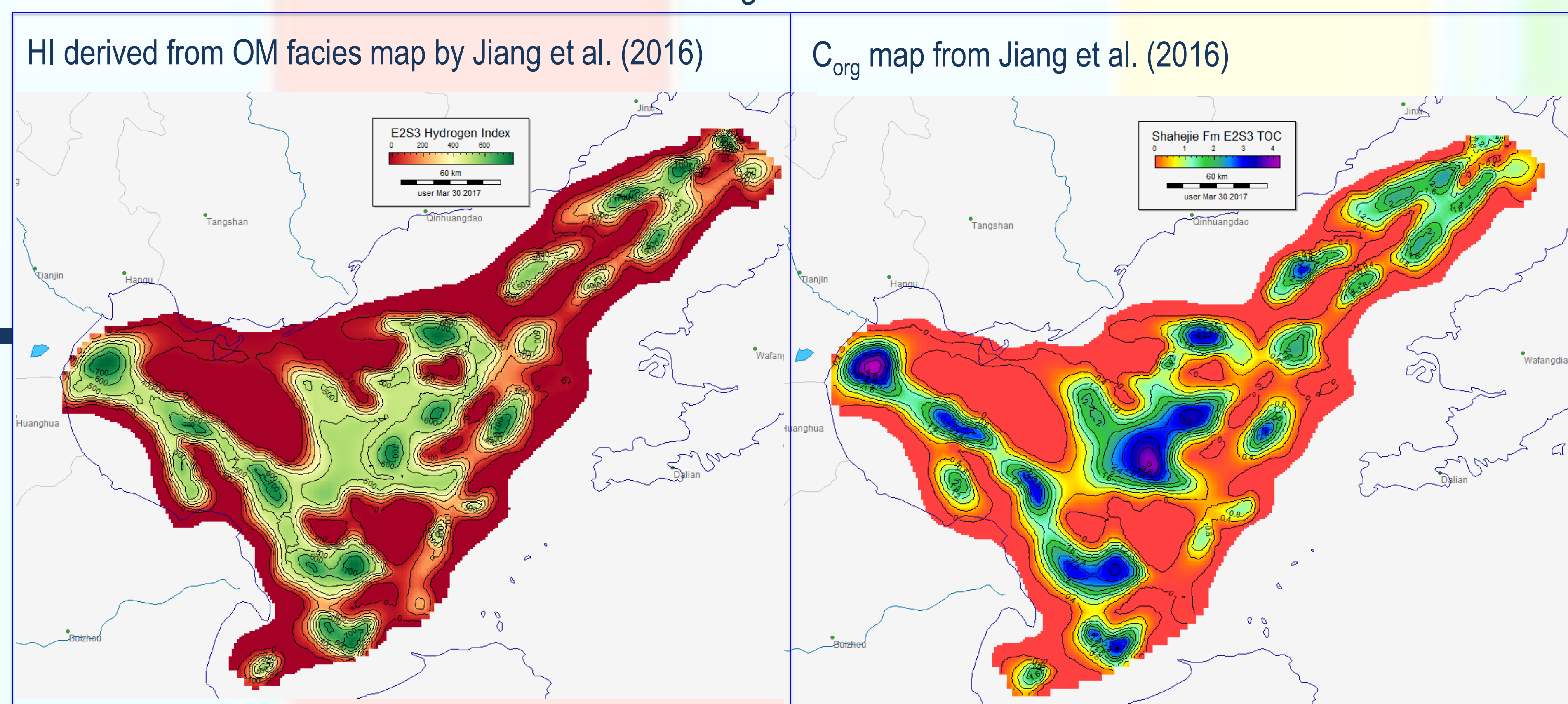
**Context:** the Bohai basin is the offshore extension in a series of prolific oil-producing basins in NE China

## Map Components

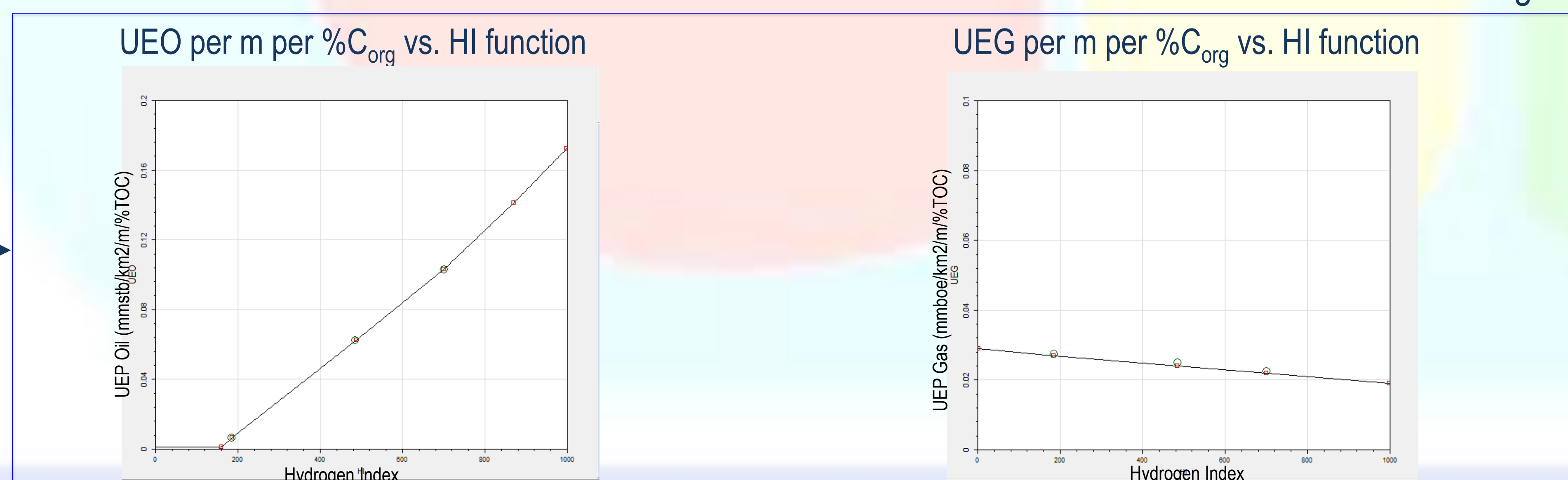
### Isopach of Shahejie Formation, 3<sup>rd</sup> Member (E2S3)



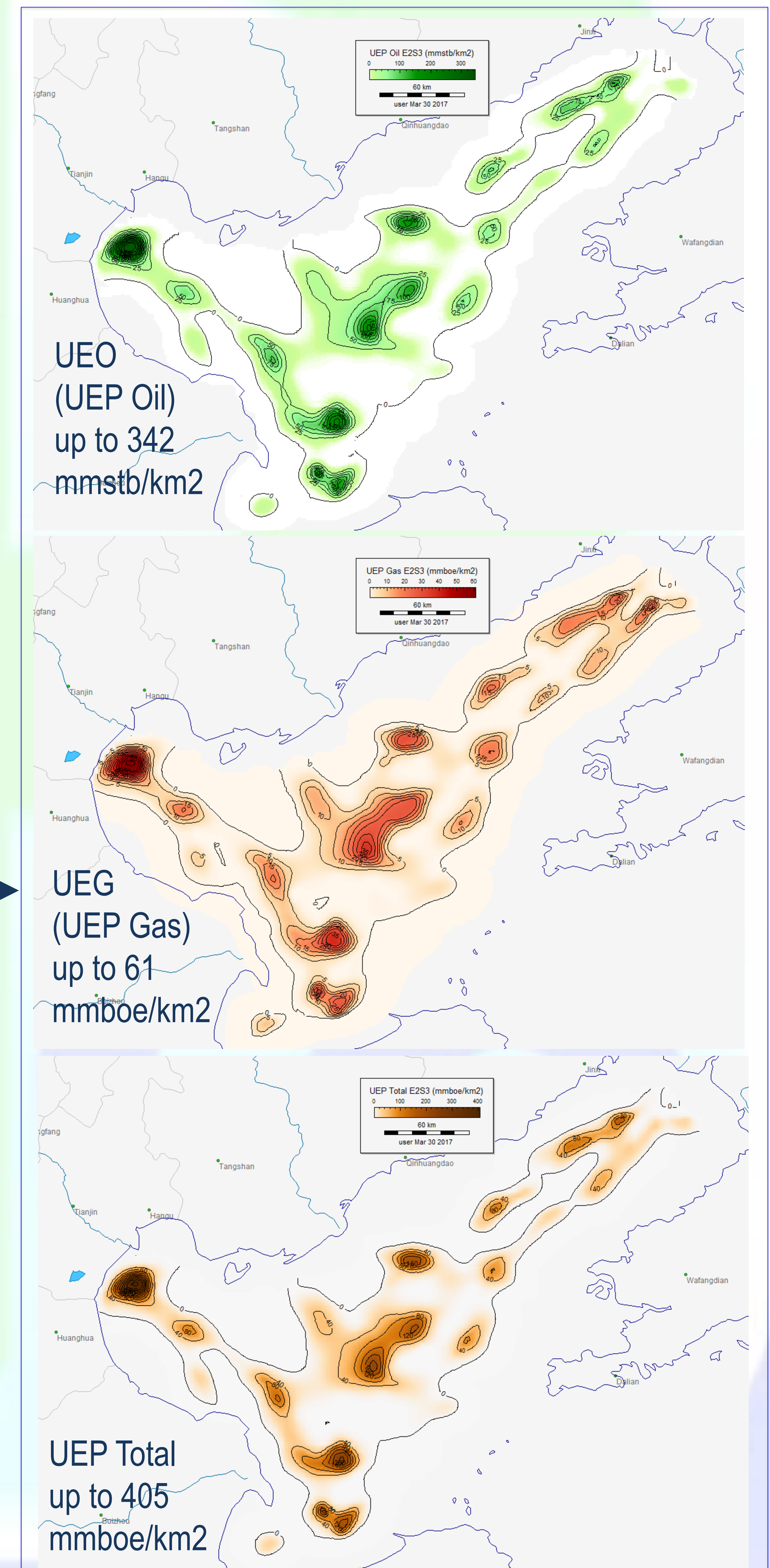
### Establish UEO/G per m per % C<sub>org</sub> using C<sub>org</sub> and HI maps

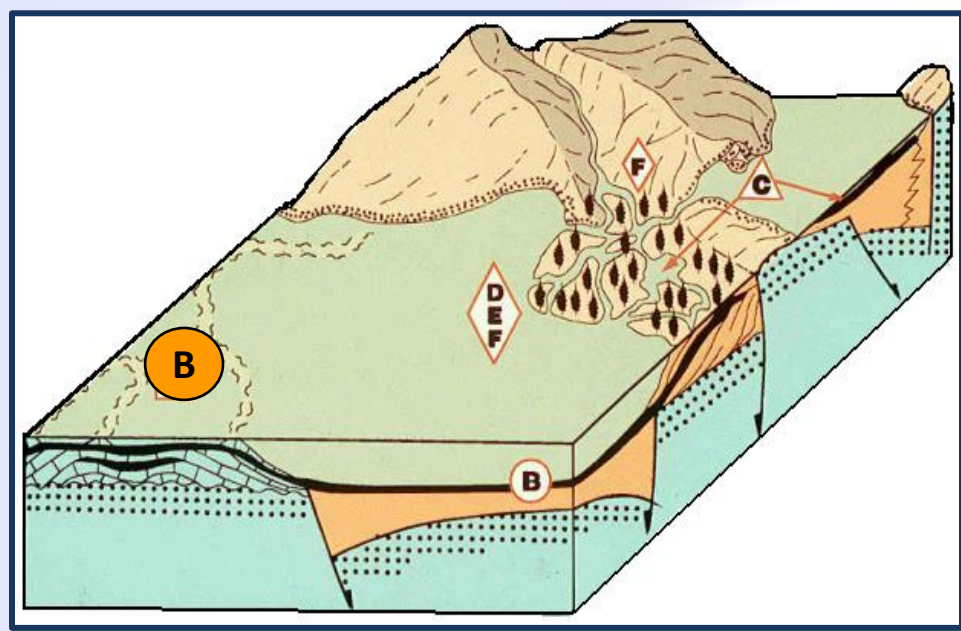


### Establish UEO/G 'scalar' vs. HI to apply to map of UEO&G / m / % C<sub>org</sub>



## UEP Map Results





# Bakken Fm, Williston Basin: aquatic marine Organofacies B



**Age:** Lower: latest Devonian (Fammenian) & Upper: earliest Carboniferous (Mississippian)

**Lithology:** pyritiferous, non-calcareous, black, clay-rich mudtones

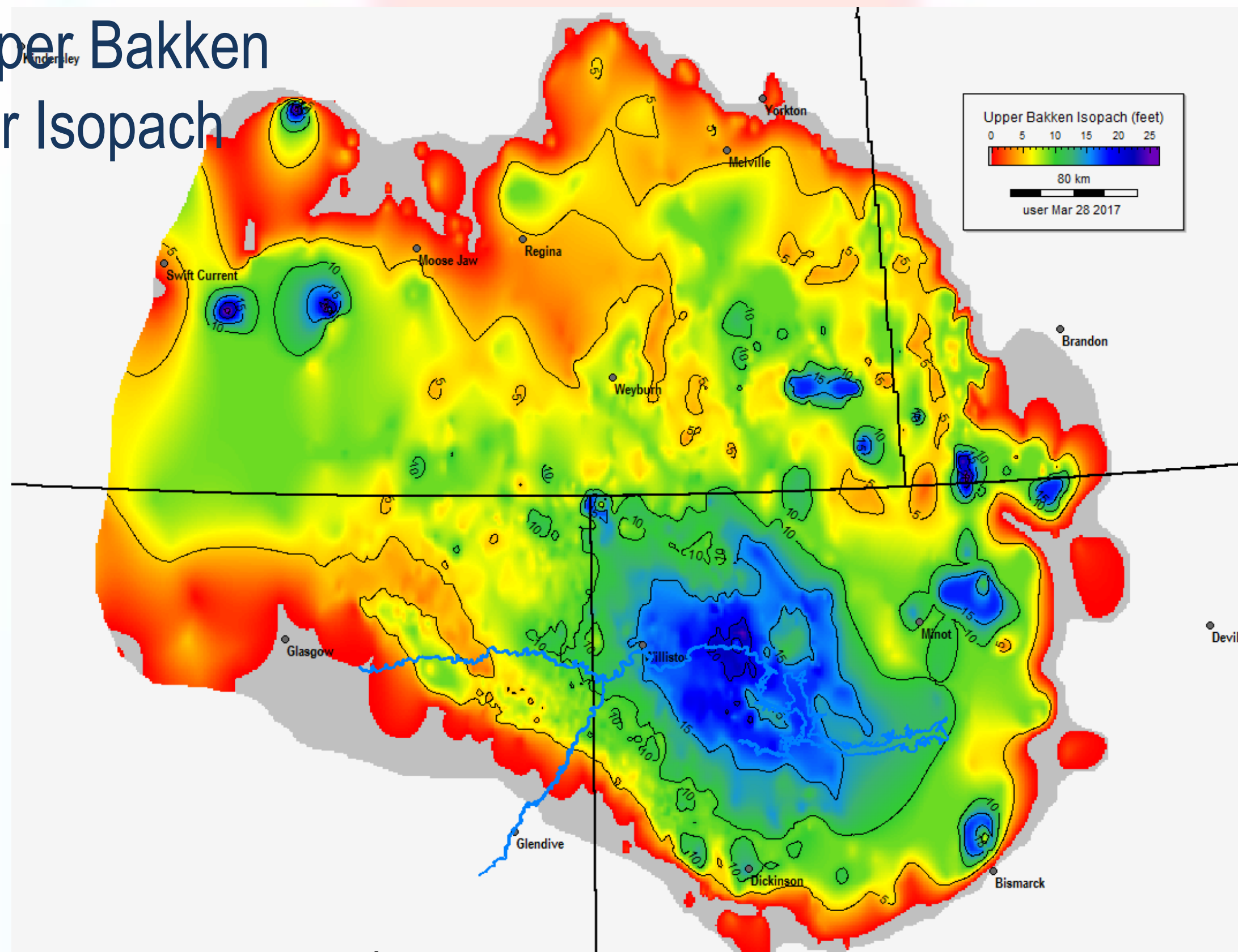
**EOD:** below wave base during marine transgressions into a shallow, silled embayment

**Context:** source rocks above & below the Middle Bakken Mbr reservoir, the world's largest tight oil endowment

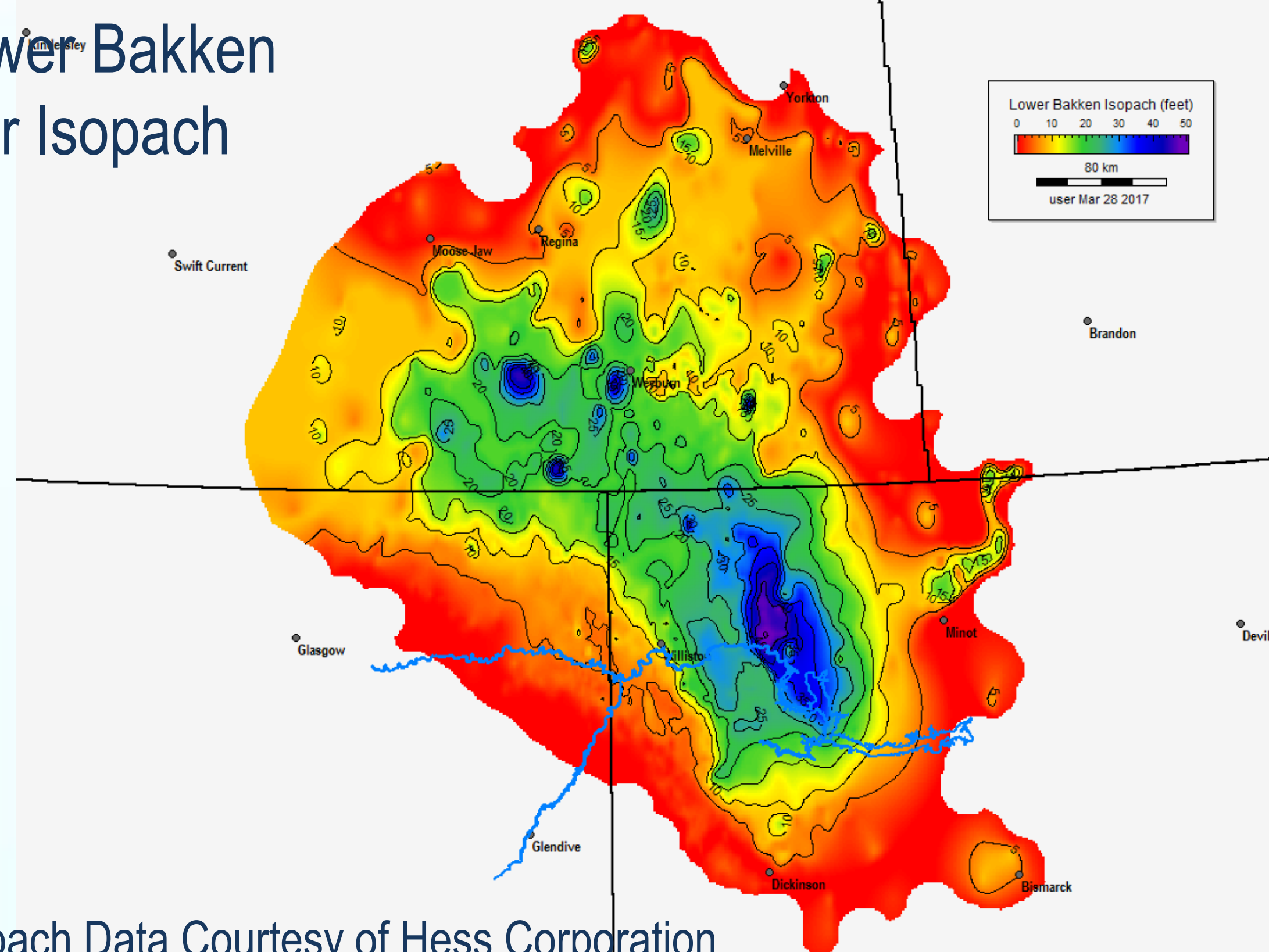
## Map Components

Workflow as per Bazhenov ( $C_{org}$  map not shown)

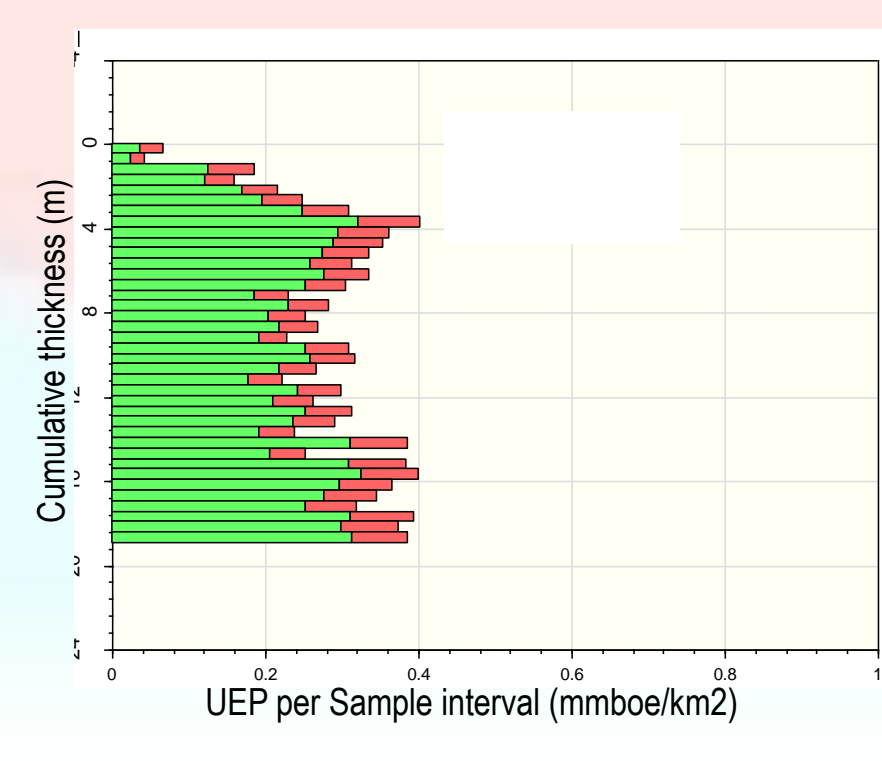
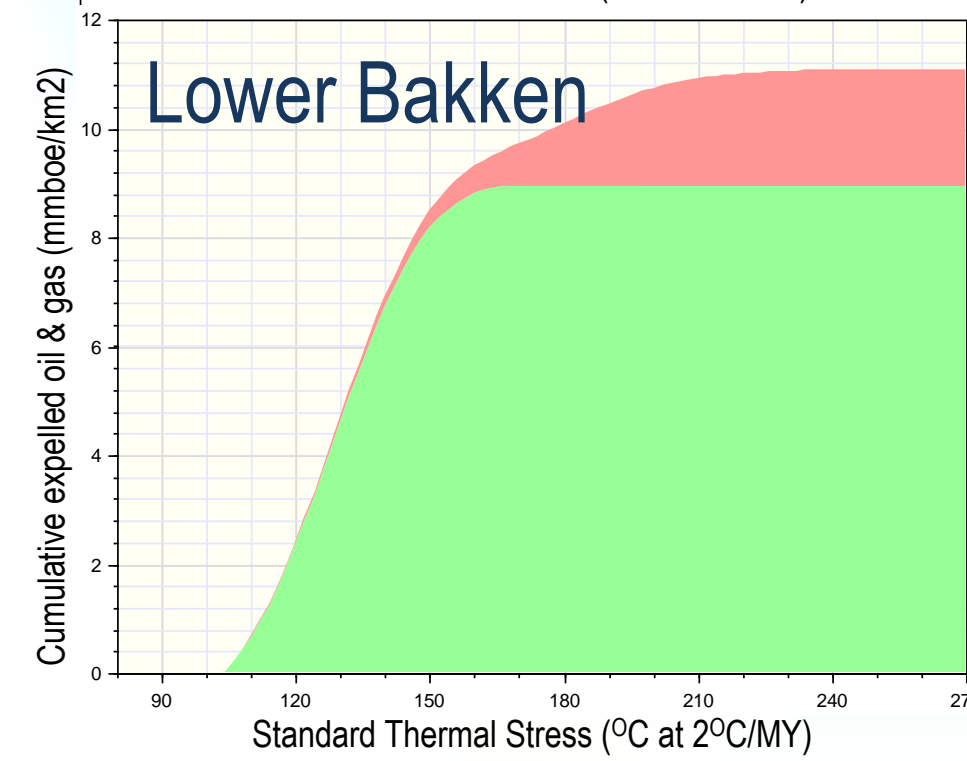
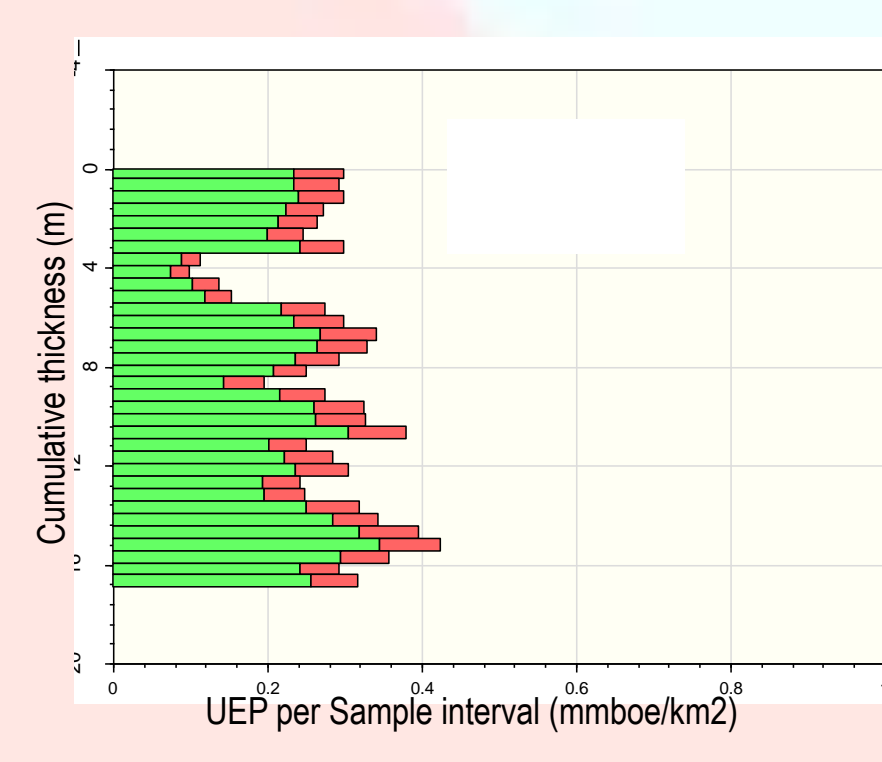
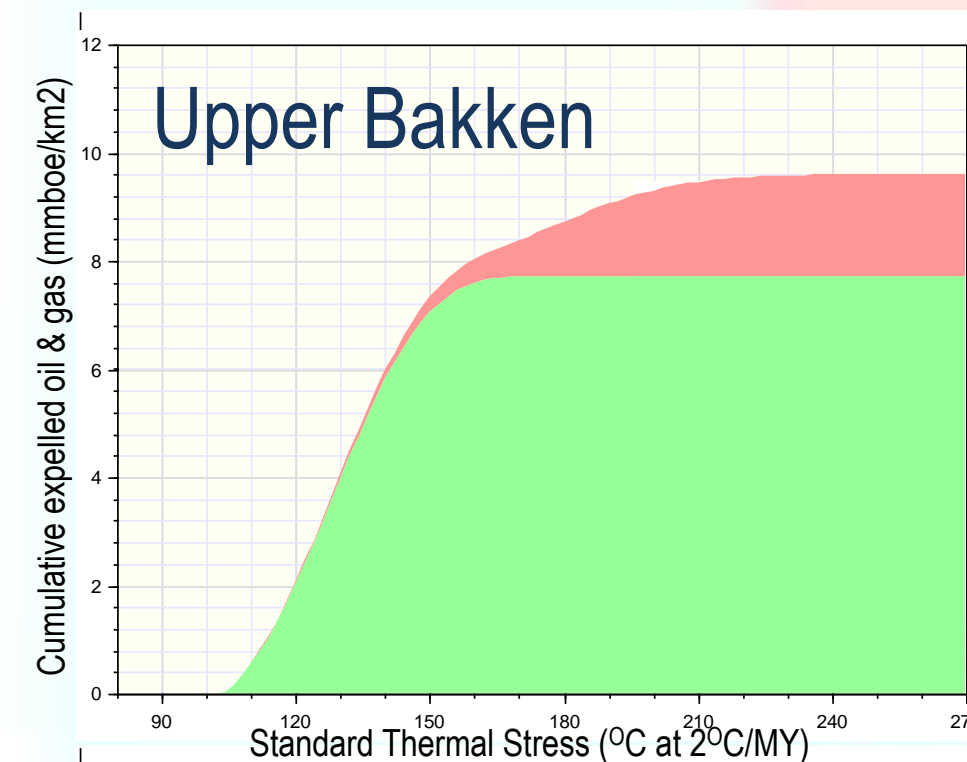
Upper Bakken  
Mbr Isopach



Lower Bakken  
Mbr Isopach



Isopach Data Courtesy of Hess Corporation



Pre-expulsion maturity SR data from cores in the Parshall Field

## UEP Map Results

UEO (UEP Oil)  
Upper Bakken Mbr  
up to 13.6 mmstb/km2

UEG (UEP Gas)  
Upper Bakken Mbr  
up to 3.2 mmboe/km2

UEO (UEP Oil)  
Lower Bakken Mbr  
up to 13.5 mmstb/km2

UEG (UEP Gas)  
Lower Bakken Mbr  
up to 3.5 mmboe/km2

UEO (UEP Oil)  
combined Mbrs  
up to 20.6 mmstb/km2

UEG (UEP Gas)  
combined Mbrs  
up to 5.4 mmboe/km2

UEP (Oil & Gas)  
up to 25.9 mmboe/km2

# Comparison of the UEP of the Source Rocks

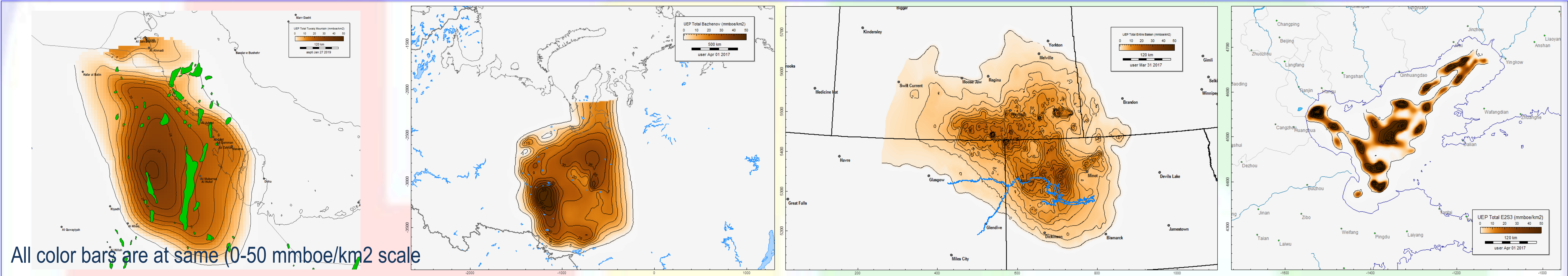


Arabian Basin

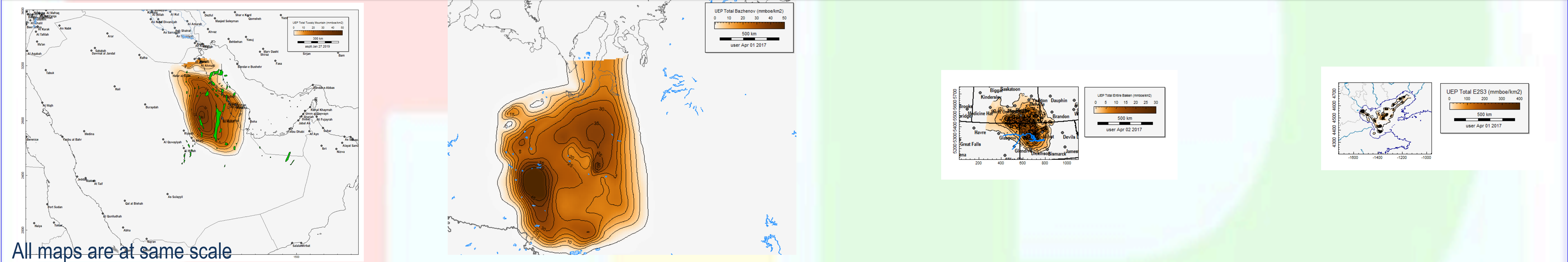
West Siberian Basin

Williston Basin

Bohai Basin



All color bars are at same (0-50 mmboe/km2 scale)



All maps are at same scale

Source Rock	Tuwaiq Mountain Fm	Bazhenov Fm facies of Volgian	Bakken Fm, combined Upr & Lwr Mbrs	Shahejie Fm, 3rd Member (E2S3)
Organofacies	A	A/B	B	Cf
Depositional area _1000 km2	340	1750	206	61*
Source Bed GRV _km3	14,320	49,145	1,029	5,240*
Thickness: mean (max) _m	45 (150)	24 (60)	4 (23)	102* (719)
C <sub>org</sub> : mean (max) _wpc	5.7 (14.0)	15.5 (29.0)	15.0 (35.3)	2.9* (4.2)
HI <sub>0</sub> : mean (max) _wptC	705 (841)	650 (812)	817 (1090)	380* (782)
UEP/m: mean (max) _mmboe/km2/m	0.25 (n/a)	0.65 (1.12)	1.13 (2.82)	0.15* (0.57)
UEO: mean (max) _mmboe/km2	9.1 (30)	12.2 (43)	3.3 (21)	7.9* (364)
UEP: mean (max) _mmboe/km2	11.1 (37)	16.1 (57)	4.4 (26)	14.9* (405)
Basinwide UEP (UEO) _bnboe	3,509 (2,893)	31,500 (24,200)	1,056 (814)	568 (429)
Gas fraction mean (min) _boefr	.19(.18)	.24(.25)	.25(.19)	.47(.10)

\* Area includes bald highs but thickness, C<sub>org</sub> and HI statistics are calculated for the non-zero isopach

Marine source rock condensation: thick and rich source beds are rare, C<sub>org</sub>, HI, UEP / m inversely correlate with thickness  
Rift-hosted lacustrine source rocks can be extremely thick with high UEP in basin center, but limited in small deep lake area  
Bakken not “world class” compared to Tuwaiq Mtn or Bazhenov, but adequate given reservoir proximity and minimal losses