Source Potential and Reservoir Fabric of the Cambay Shale, Cambay Basin: A Potential Tight Gas/Tight Oil Resource for India*

Mateen Hafiz[1]

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Abstract

The Eocene Cambay Shale is the principal source rock for conventional hydrocarbons and a prime target for tight gas/tight oil exploration in the Cambay Basin (western India). In this study, samples of the Cambay Shale from four wells and two open-cast coal mines were examined for total organic carbon (TOC) content, visual kerogen analysis (VKA), and thermal maturity (Ro). The mineralogy and texture of the shale were quantified using X-Ray Diffraction (XRD) and Quantitative Evaluation of Minerals by SCANning Electron Microscopic (QEMSCAN) techniques and the reservoir fabric, pore types, and networks were analyzed using Field Emission Gun – Scanning Electron Microscopic (FEG-SEM) imaging. The Cambay Shale samples are organic rich (0.37-10.68 wt.% TOC and avg. 2.43 wt.%), with fair to excellent source potential from dominantly type III kerogen, deposited in dysoxic to anoxic bottom water conditions in a brackish environment. The Ro values range from 0.58% to 0.7%, indicating that the organic matter is in the oil generation window. The XRD and QEMSCAN data show that kaolinite, illite, and quartz are the major constituents of the shale, with an average content of 33, 15 and 11 wt.% respectively. This implies a very low Brittleness Index (BI) with an average value of 0.15. The SEM images show the dominance of organic matter hosted pores (organopores), but also an abundance of intraparticle and interparticle pores of varying shapes associated with mineral matrix. The pores are generally less than 1 μm across, but some of the organopores are more than 1 μm in size. The organopores, interparticle, and intercrystalline-intraparticle pores within pyrite framboids and concretions are the primary contributors to the effective fluid storage and, potentially, to hydrocarbon flow. The integration of geochemical and petrophysical data confirms that the Cambay Shale has all the essential source and reservoir characteristics necessary for tight gas/tight oil production, but that the high clay content and consequent low brittleness of the formation may reduce the ability to hydraulically fracture the shale and so limit well productivity.

References Cited

Kuuskraa, V.A., S.H. Stevens, and K. Moodhe, 2013, Cambay Basin, India: EIA/ARI World Shale Gas and Shale Oil Resource Assessment: Advanced Resources International, Inc., Arlington, VA, p. XXIV-7 – XXIV-14.

Mishra, S., and B.K. Patel, 2011, Gas Shale Potential of Cambay Formation, Cambay Basin, India: The 2nd South Asian Geoscience Conference and Exhibition, GEOIndia 2011, 12-14 January 2011, Greater Noida, New Delhi, India, 5 p.

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Mateen Hafiz | October 18, 2017

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AAPG/SEG 2017 ICE LONDON

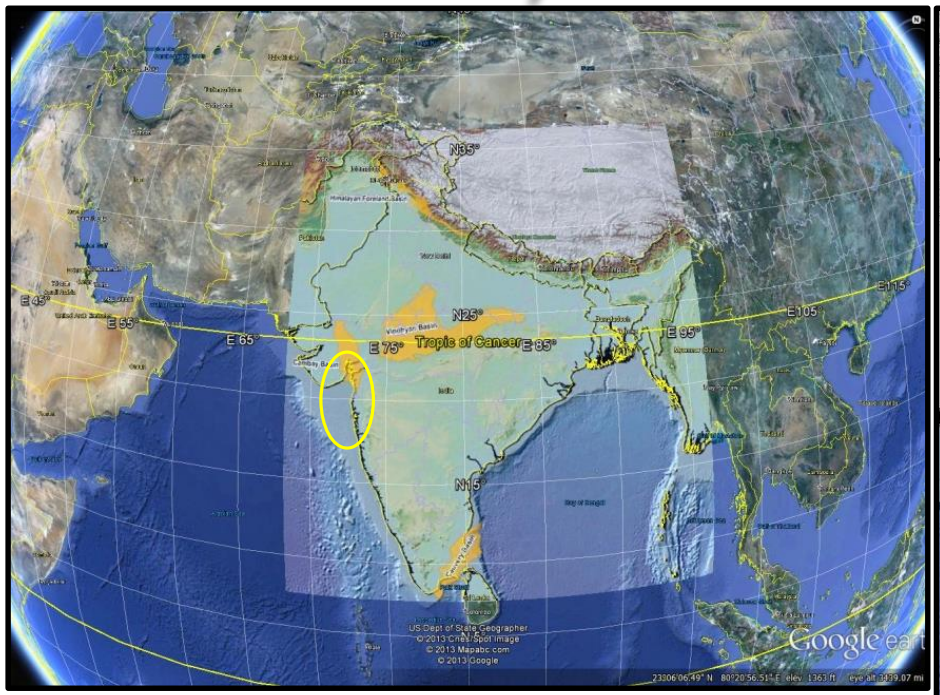
EGI Energy & Geoscience Institute AT THE UNIVERSITY OF UTAH

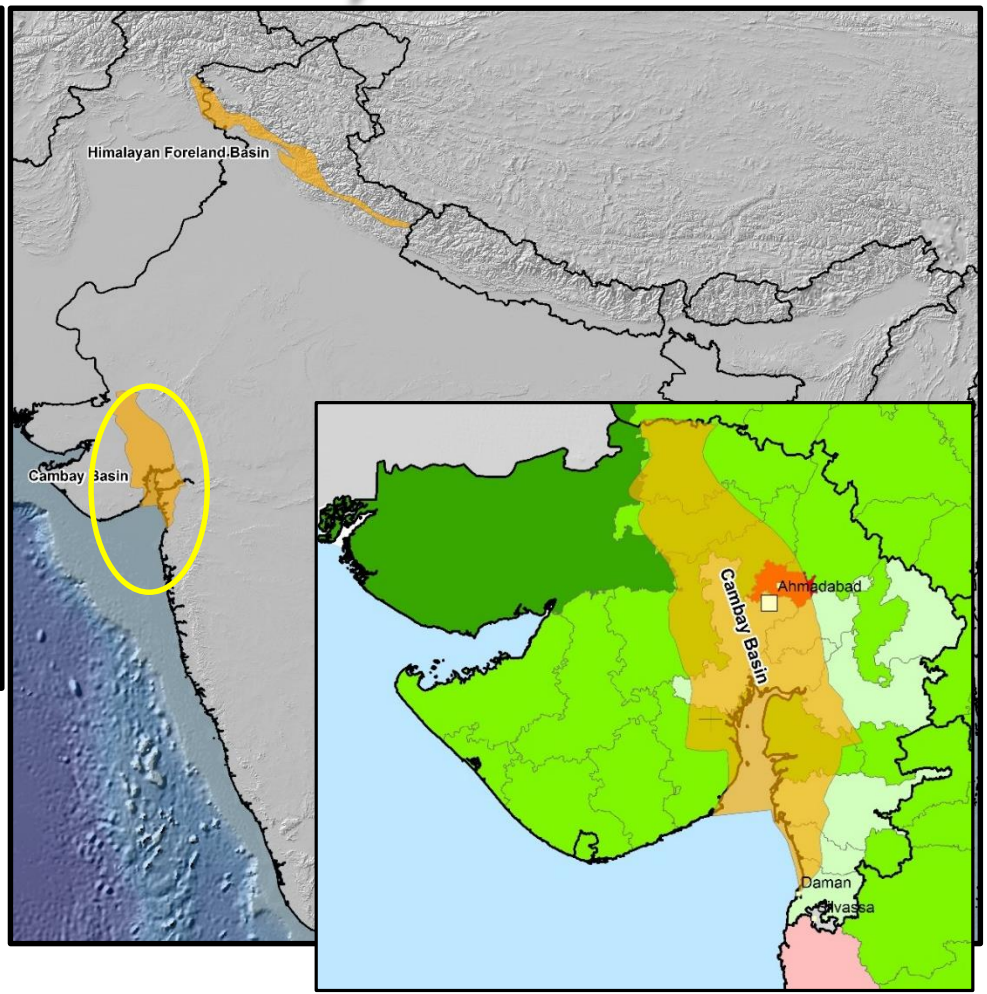
Institute of Energy Research & Training IERT University of Jammu

Presentation Layout

- ❑ **Location and Geological Setting of the Basin**
- ❑ **Analytical Results**
  - ❑ **Source Rock Geochemistry** - Rock Eval, TOC, Ro, Visual Kerogen Analysis
  - ❑ **Petrofabric** - XRD, Thin section study, QEMSCAN, SEM
- ❑ **Summary**

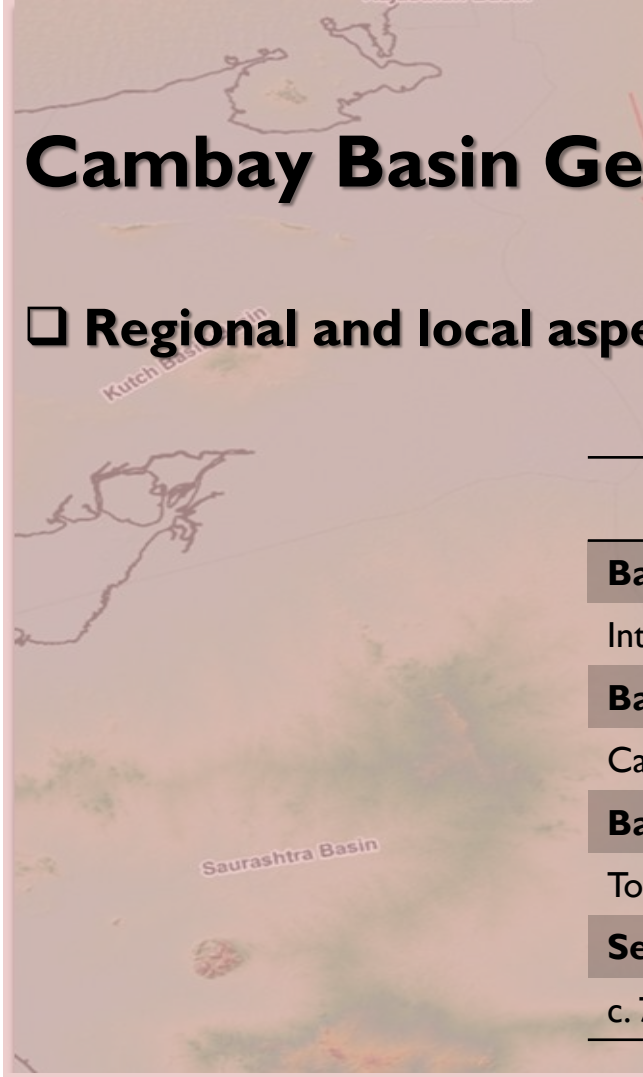
Physical Location of Cambay Basin





Cambay Basin Geology

- **Regional and local aspects**



Cambay Basin Origin	
Basin Origin	**Time/Age**
Intra-Cratonic Rift Basin	Cretaceous
Basin Category	
Category I (Proven, Commercially Productive)	
Basin Area (sq. Km)	
Total 53,500 (Onshore 5100 sq. Km & Offshore 2500 sq. Km)	
Sediment Thickness	
c. 7 -11 Km of sediment has accumulated in the basin	

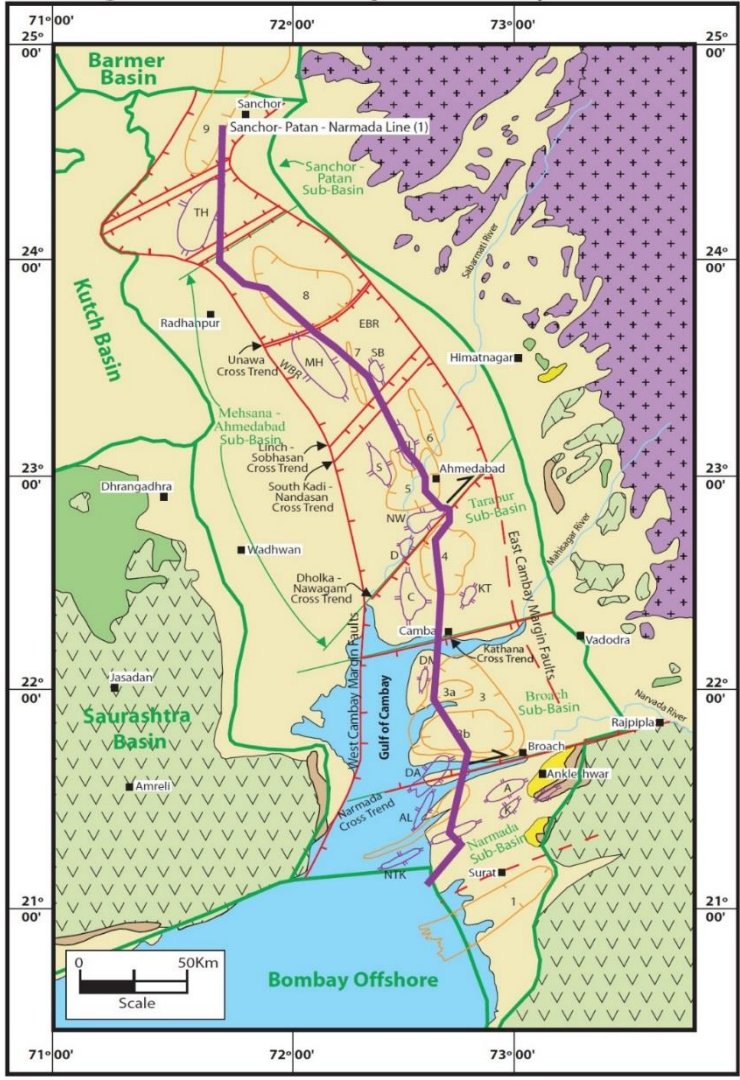
Cambay Basin – Geological/Structural Transect

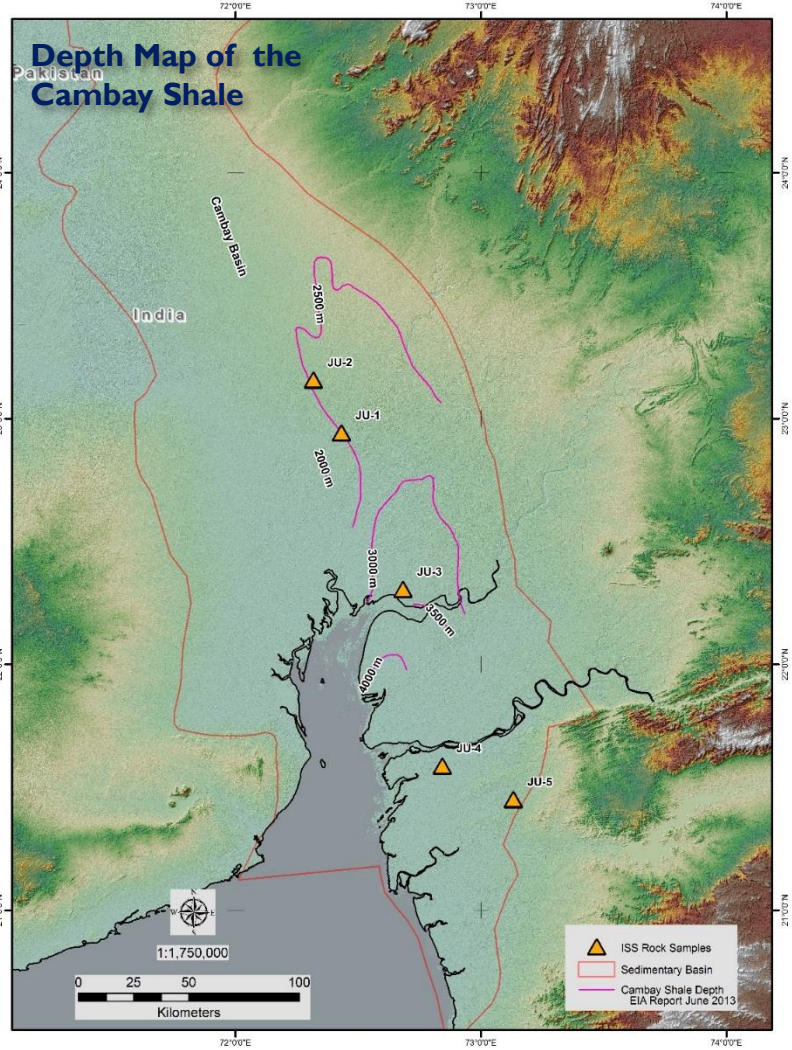
- The basin is segmented by E-W trending transverse faults into five tectonic blocks
  - Patan - Sanchor Block
  - Mehsana - Ahmedabad Block
  - Tarapur Block
  - Broach Block
  - Narmada Block

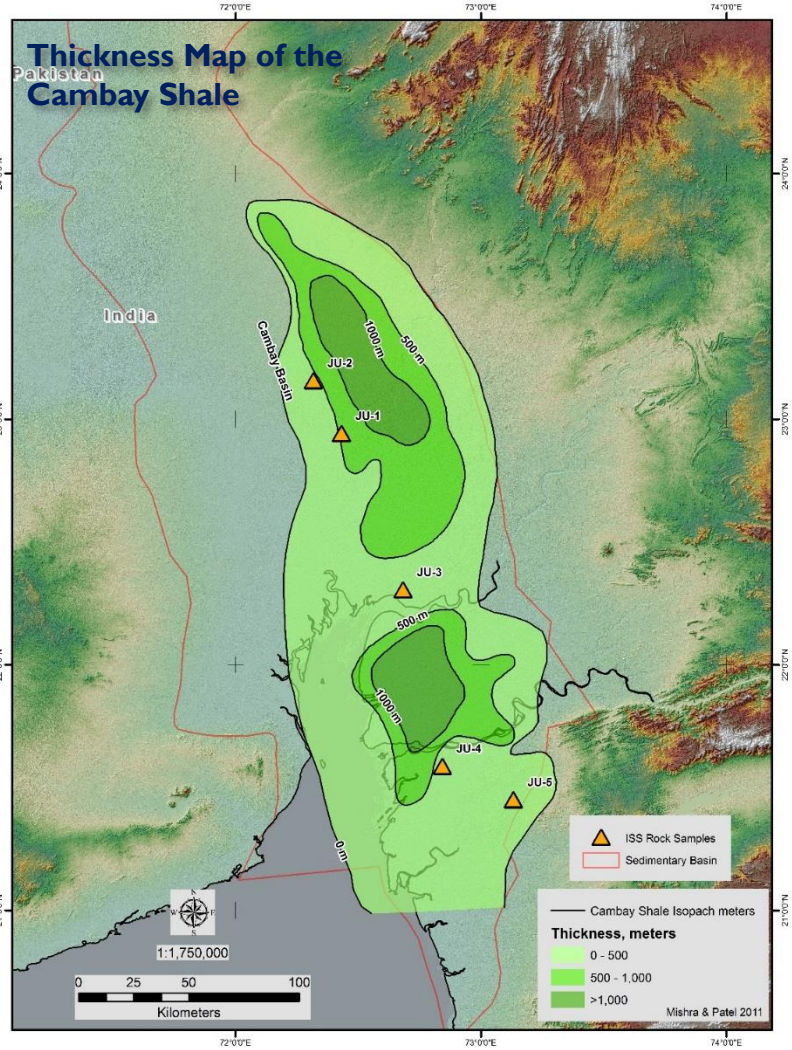
Structural Highs	Depressions
NTK - North Tapi-Kosamba AL - Aliabat K - Kosamba A - Anklesvar DA - Dahej DM - Devla - Malpur KT - Kathana C - Cambay D - Dholka NW - Nawagam-Wasna KL - Kalol S - Sanand SB - Sobhasan MH - Mehsana High EBR - East Basin Rise WBR - West Basin Rise TH - Tharad	1. Dumas - Surat 2. Narmada 3. Broach-Jambusar 3a. Broach Low 3b. Tankari Low 4. Cambay-Tarapur 5. Ahmadabad-Mehsana 6. Wavel 7. Waroson 8. Patan-Tharad 9. Sanchore

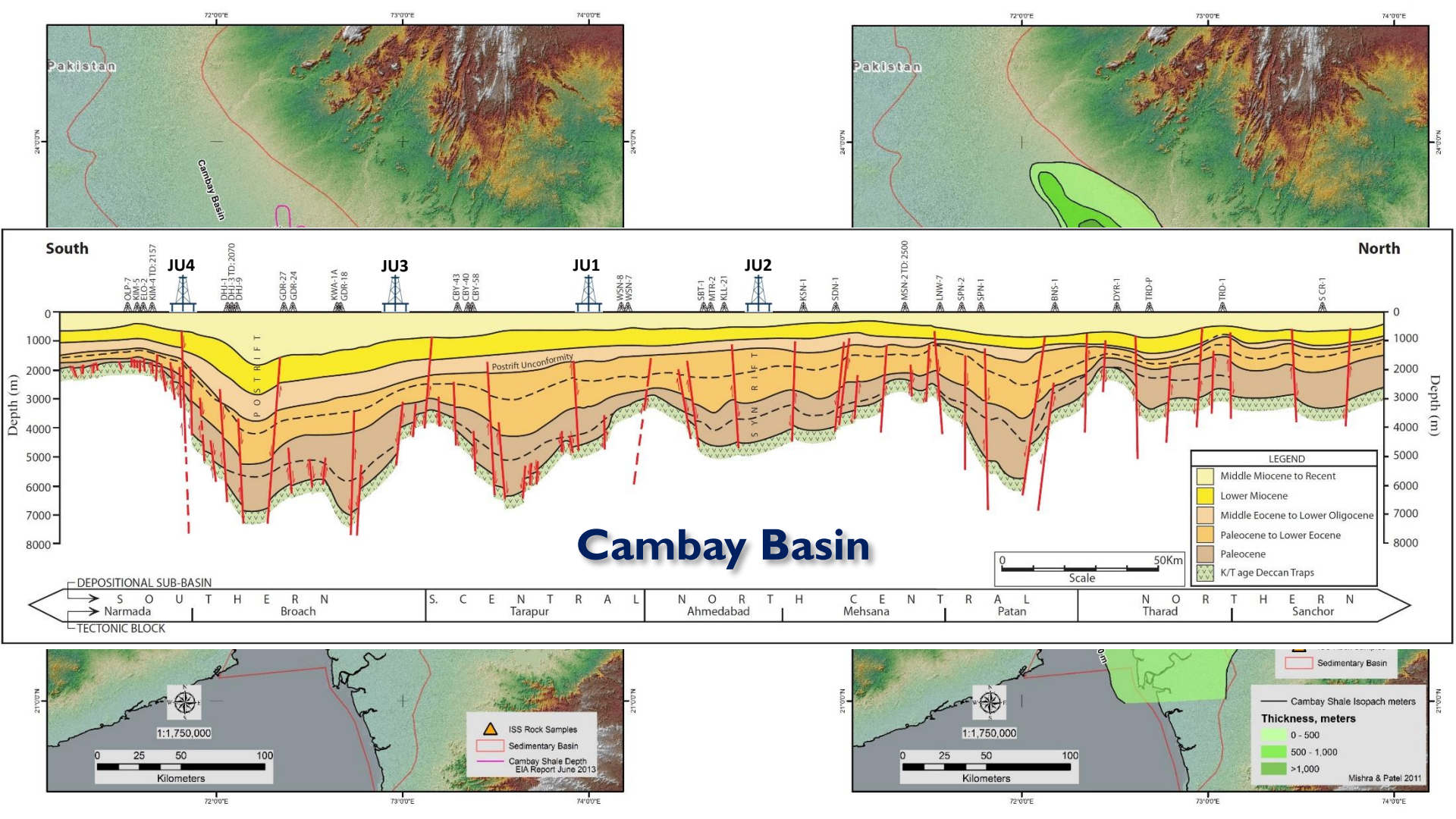
Legend

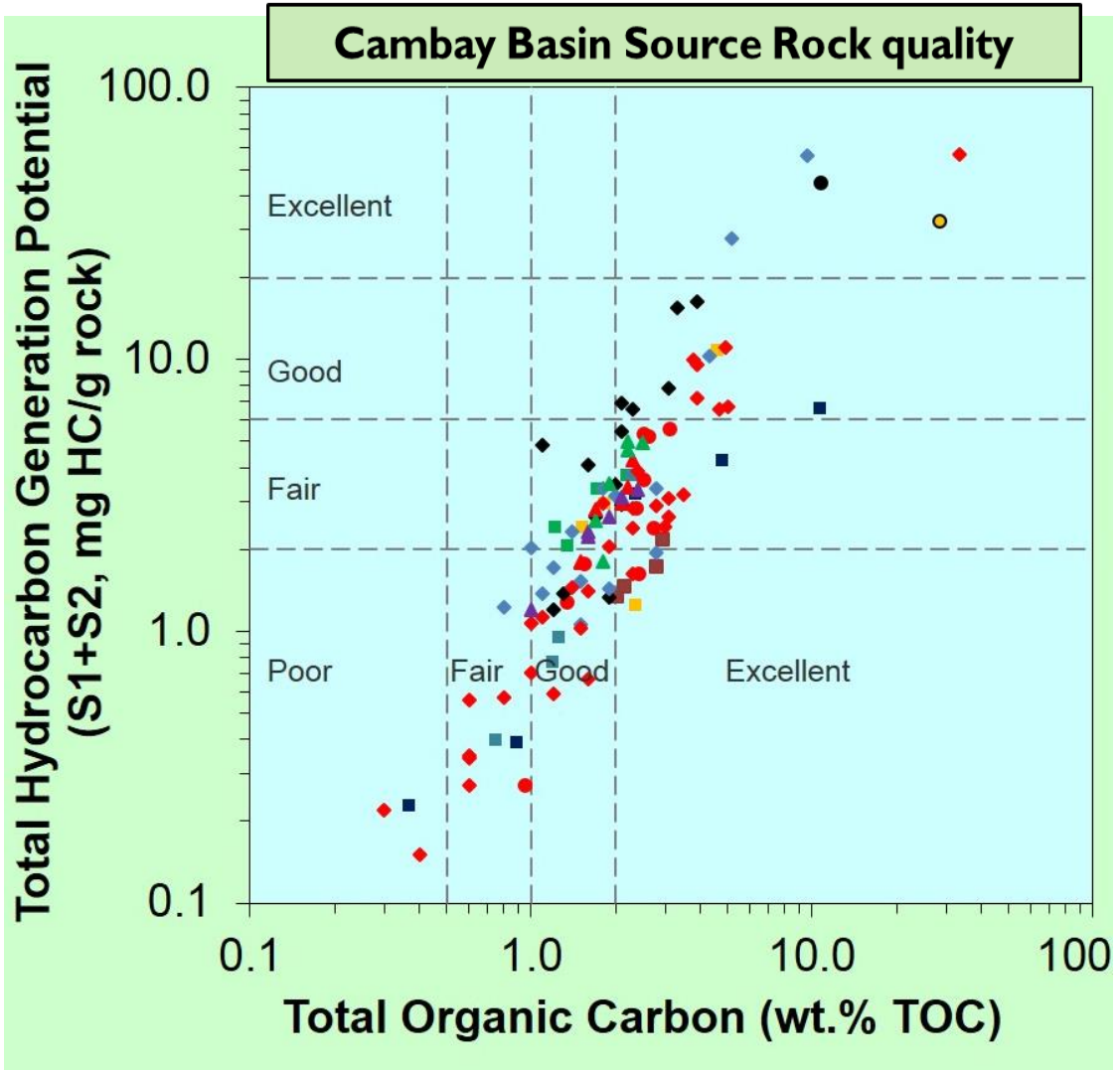
- Quaternary
- Neogene
- Paleogene
- Cretaceous
- Late Cretaceous Deccan Traps
- Pre-Cambrian Continental Crust



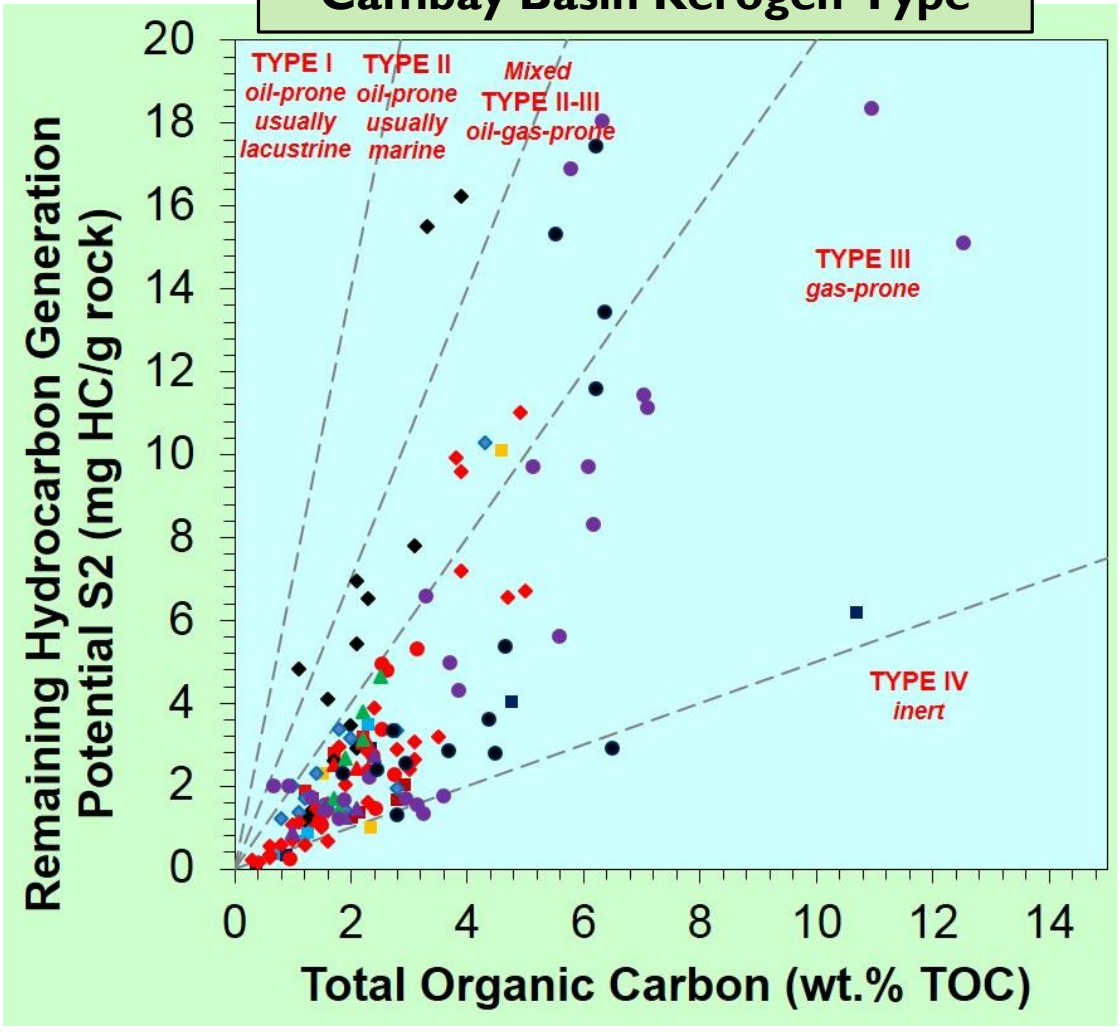

Depth Map of the Cambay Shale
Pakistan
India
Cambay Basin
2500 m
2000 m
3000 m
3500 m
4000 m
JU-1
JU-2
JU-3
JU-4
JU-5
1:1,750,000
0 25 50 100
Kilometers
ISS Rock Samples
Sedimentary Basin
Cambay Shale Depth
EIA Report June 2013


Thickness Map of the Cambay Shale
Pakistan
India
Cambay Basin
1000 m
500 m
0 m
JU-1
JU-2
JU-3
JU-4
JU-5
1:1,750,000
0 25 50 100
Kilometers
ISS Rock Samples
Sedimentary Basin
Cambay Shale Isopach meters
Thickness, meters
0 - 500
500 - 1,000
>1,000
Mishra & Patel 2011

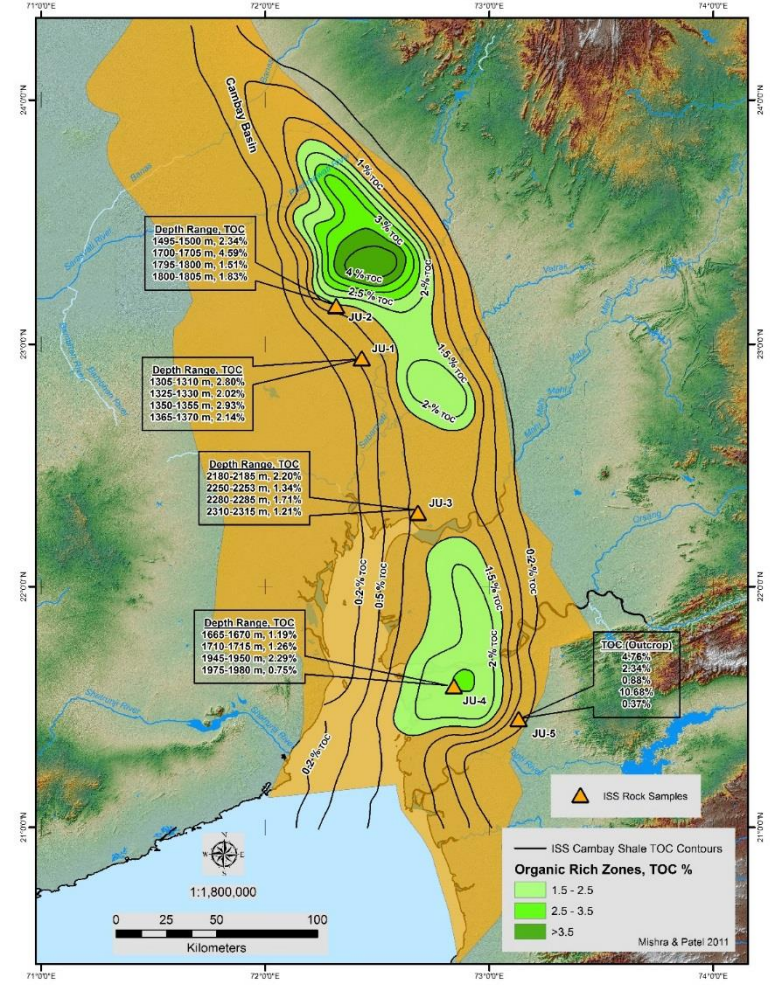

Pakistan
Cambay Basin
Pakistan
South
North
JU4
JU3
JU1
JU2
POLP-7
KIM-5
ELO-2
KIM-4 TD: 2157
DHJ-1
DHJ-3 TD: 2070
DHJ-9
GDR-27
GDR-24
KWA-1A
GDR-18
CBY-43
CBY-40
CBY-58
WSN-8
WSN-7
SBT-1
MTR-2
KLL-21
KSN-1
SDN-1
MSN-2 TD: 2500
LNW-7
SPN-2
SPN-1
BNS-1
DYR-1
TRD-P
TRD-1
S CR-1
Depth (m)
POSTRIFT
Postrift Unconformity
SYN RIFT
Cambay Basin
LEGEND
Middle Miocene to Recent
Lower Miocene
Middle Eocene to Lower Oligocene
Paleocene to Lower Eocene
Paleocene
K/T age Deccan Traps
0
50Km
Scale
DEPOSITIONAL SUB-BASIN
SOUTHERN
Narmada
Broach
S. CENTRAL
Tarapur
NORTH CENTRAL
Ahmedabad
Mehsana
Patan
NORTHERN
Tharad
Sanchor
TECTONIC BLOCK
1:1,750,000
0 25 50 100
Kilometers
ISS Rock Samples
Sedimentary Basin
Cambay Shale Depth
EIA Report June 2013
Sedimentary Basin
Cambay Shale Isopach meters
Thickness, meters
0 - 500
500 - 1,000
>1,000
Mishra & Patel 2011


Cambay Basin Source Rock quality
Total Hydrocarbon Generation Potential (S1+S2, mg HC/g rock)
100.0
10.0
1.0
0.1
Excellent
Good
Fair
Poor
Fair
Good
Excellent
0.1
1.0
10.0
100
Total Organic Carbon (wt.% TOC)

Cambay Basin Kerogen Type



Source Rock Quality & TOC Map



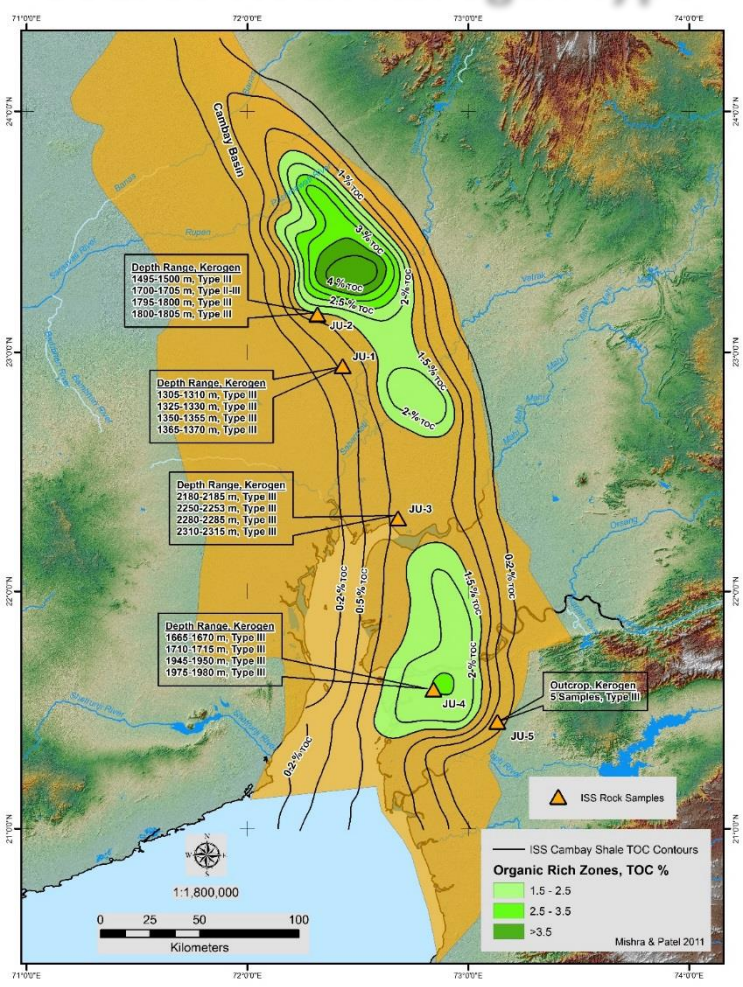
Kerogen: Type II-III & III

Avg. TOC: 2.4%

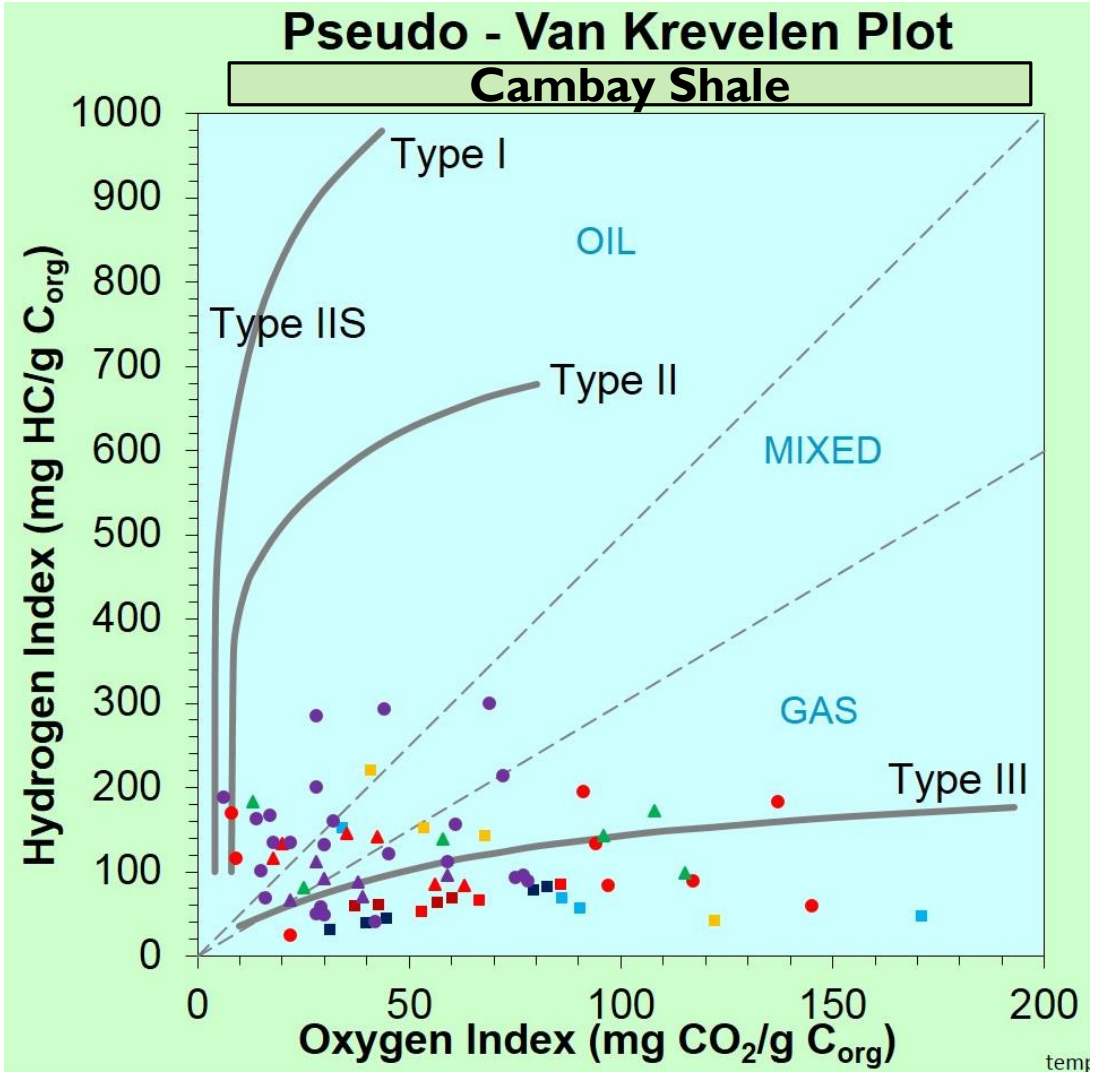
Tmax : 430- 445 °C

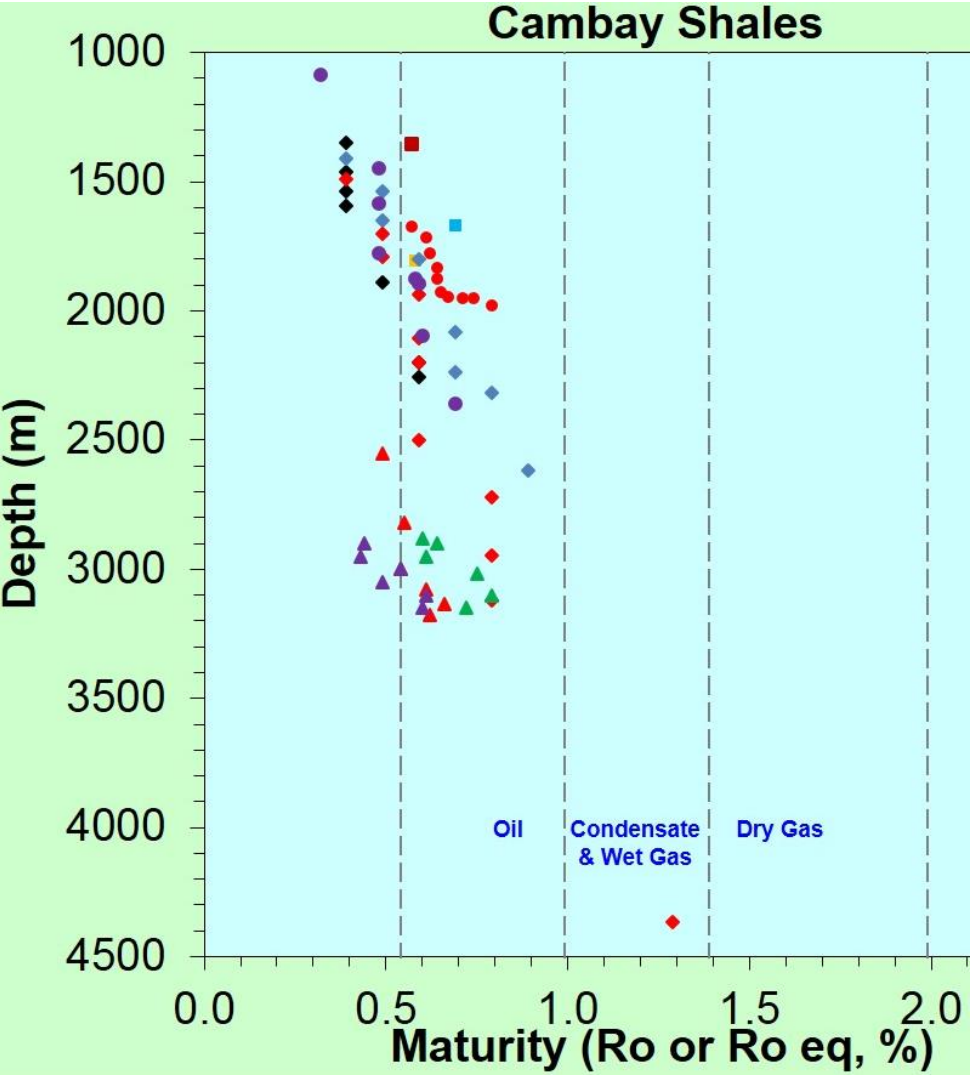
Ro: 0.59%

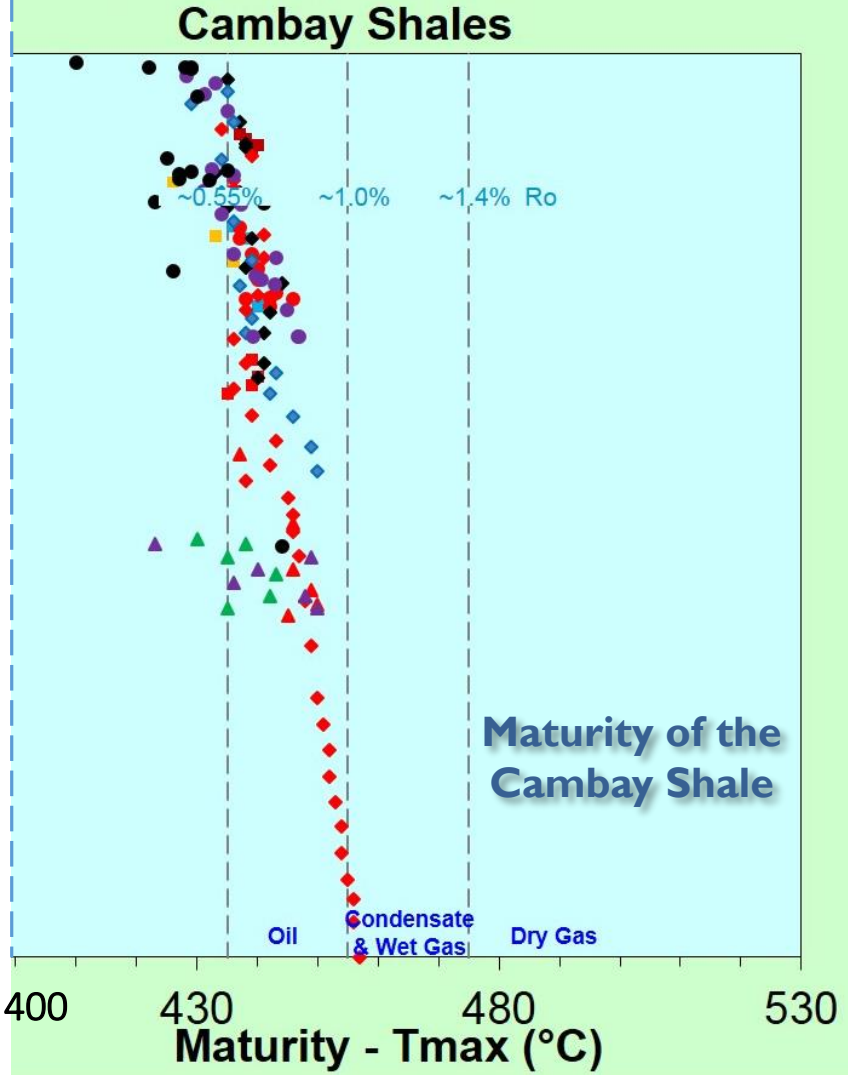
Source Rock Kerogen Type

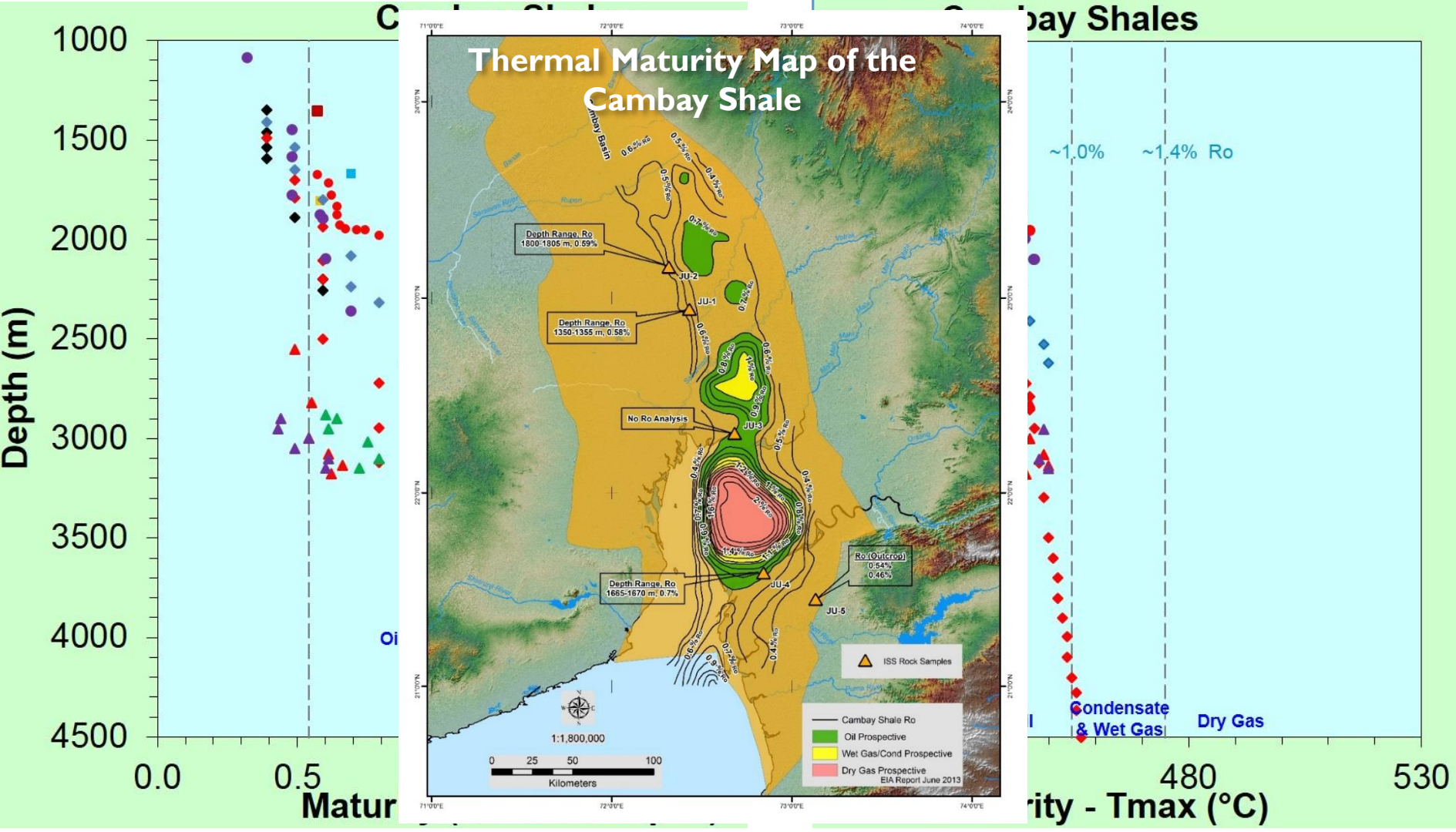


Cambay Shale Kerogen Type

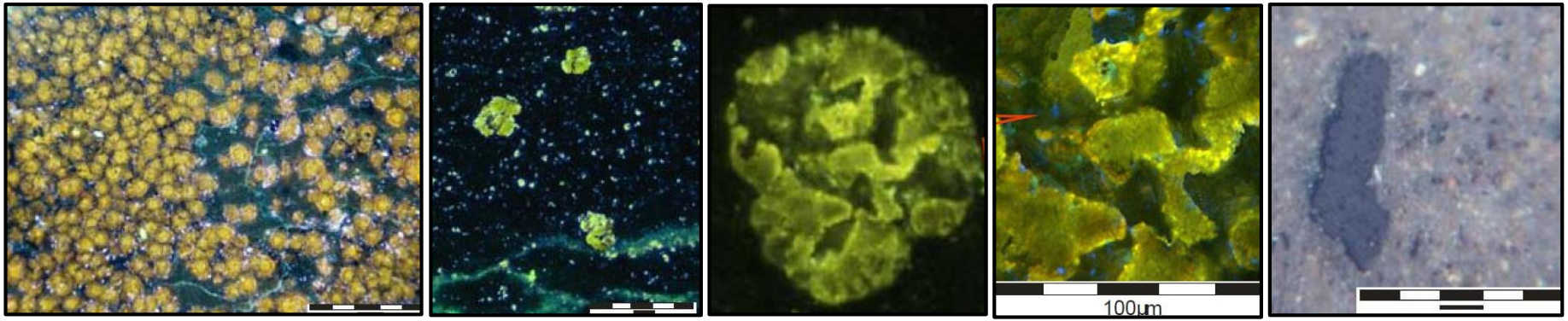



Cambay Shales
1000
1500
2000
2500
3000
3500
4000
4500
Depth (m)
Oil
Condensate & Wet Gas
Dry Gas
0.0
0.5
1.0
1.5
2.0
Maturity (Ro or Ro eq, %)

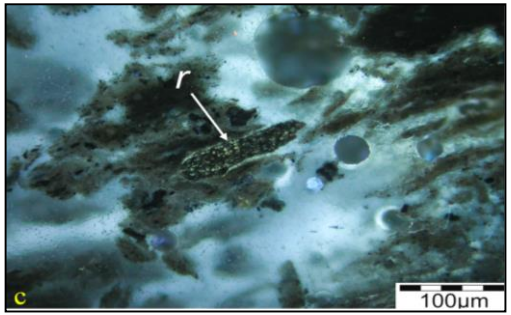

Cambay Shales
~0.55%
~1.0%
~1.4% Ro
Maturity of the Cambay Shale
Oil
Condensate & Wet Gas
Dry Gas
400
430
480
530
Maturity - Tmax (°C)


Thermal Maturity Map of the Cambay Shale
Cambay Basin
Depth Range, Ro
1800-1805 m; 0.59%
JU-2
JU-1
Depth Range, Ro
1350-1355 m; 0.58%
No Ro Analysis
JU-3
Depth Range, Ro
1665-1670 m; 0.7%
JU-4
Ro (Outcrop)
0.54%
0.46%
JU-5
ISS Rock Samples
Cambay Shale Ro
Oil Prospective
Wet Gas/Cond Prospective
Dry Gas Prospective
EIA Report June 2013
1:1,800,000
0 25 50 100
Kilometers
Depth (m)
1000
1500
2000
2500
3000
3500
4000
4500
0.0
0.5
Matur
~1.0%
~1.4% Ro
Condensate
& Wet Gas
Dry Gas
480
530
rity - Tmax (°C)

Visual Kerogen Characterization of Cambay Shale

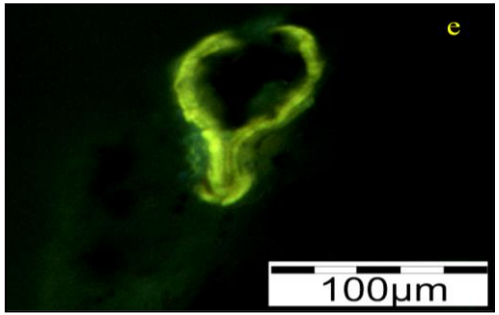


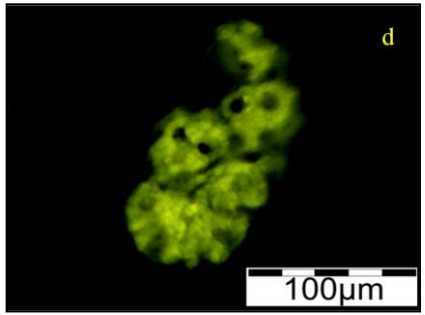
Photomicrographs of alginate (Botryococcus brauni) in UV light (dry lenses) & Vitrinite in reflected white light (oil immersion)



Vitrinite with tiny yellow resinites in UV light

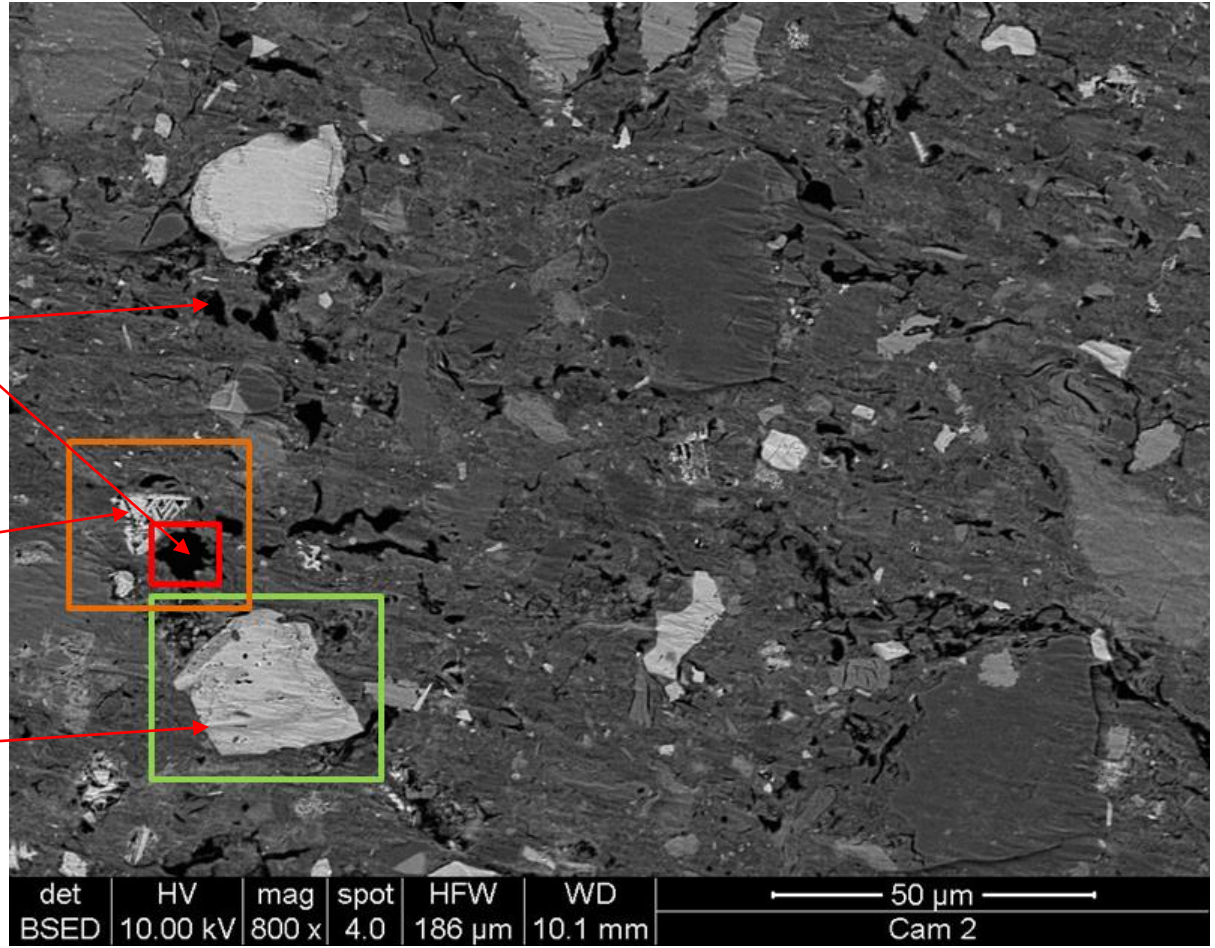
Liptinites in UV light (dry lenses)

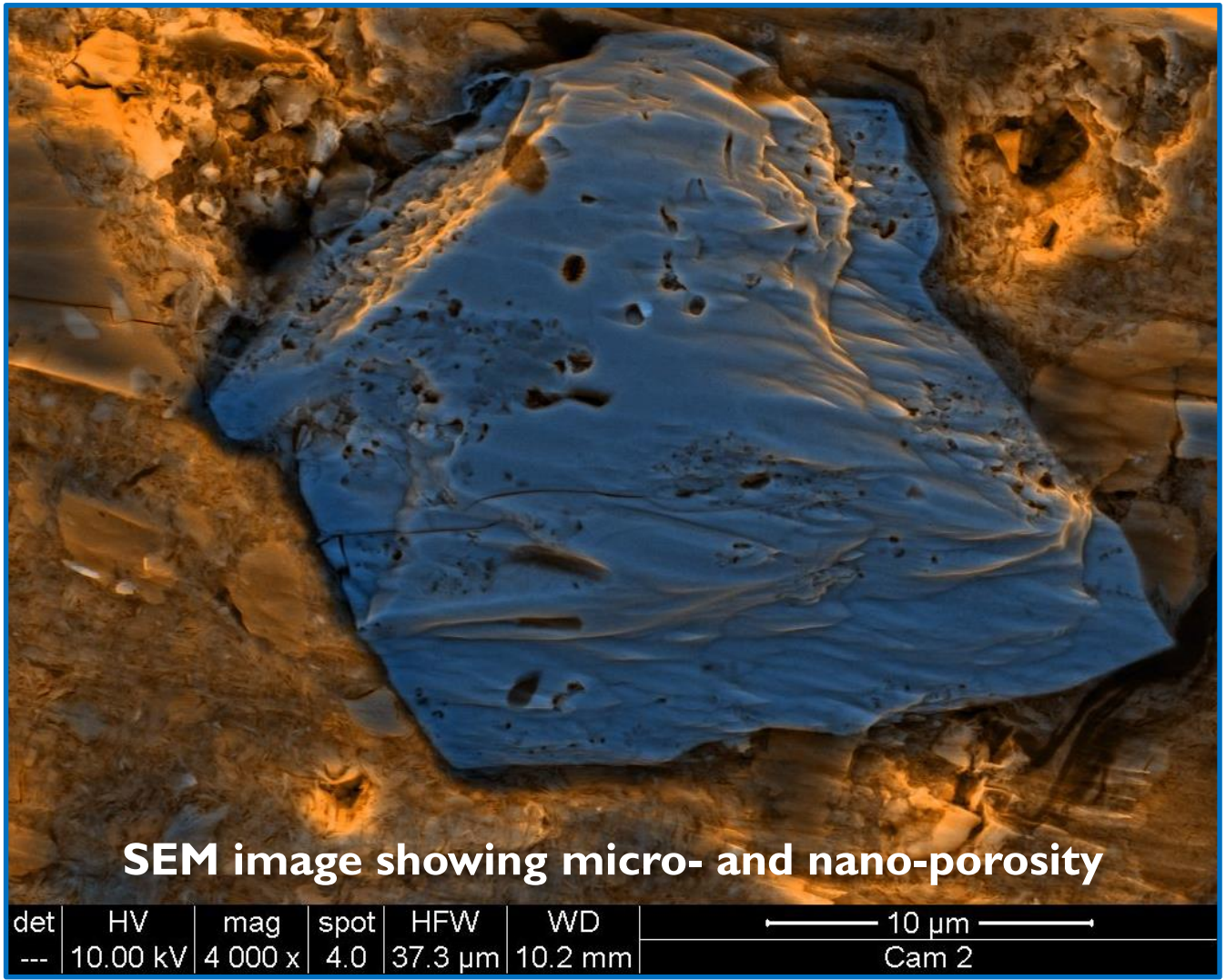




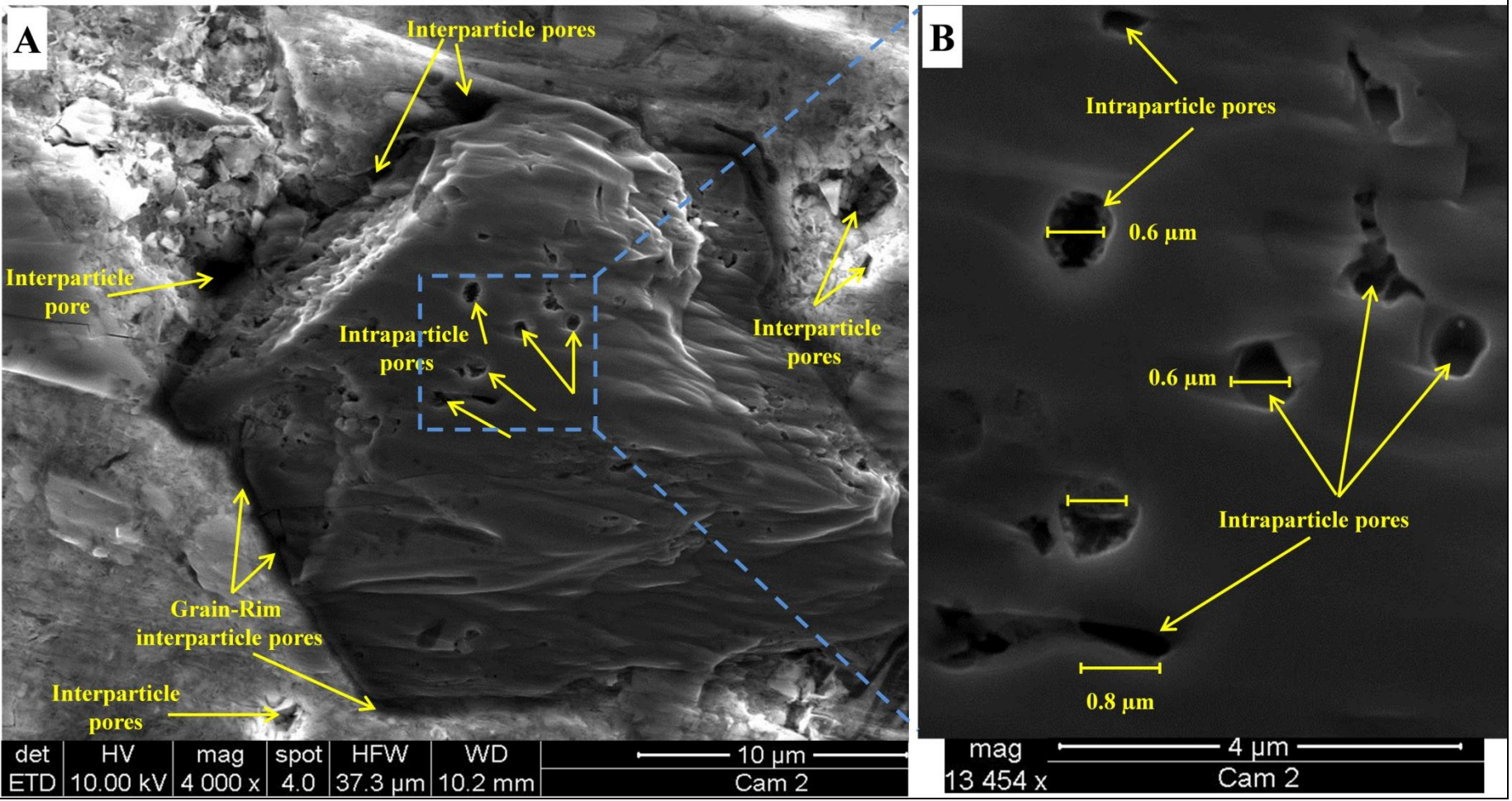
Alginite and sporinite in UV light (dry lenses)

Scanning Electron Microscopy (SEM), Micro-and Nano-porosity

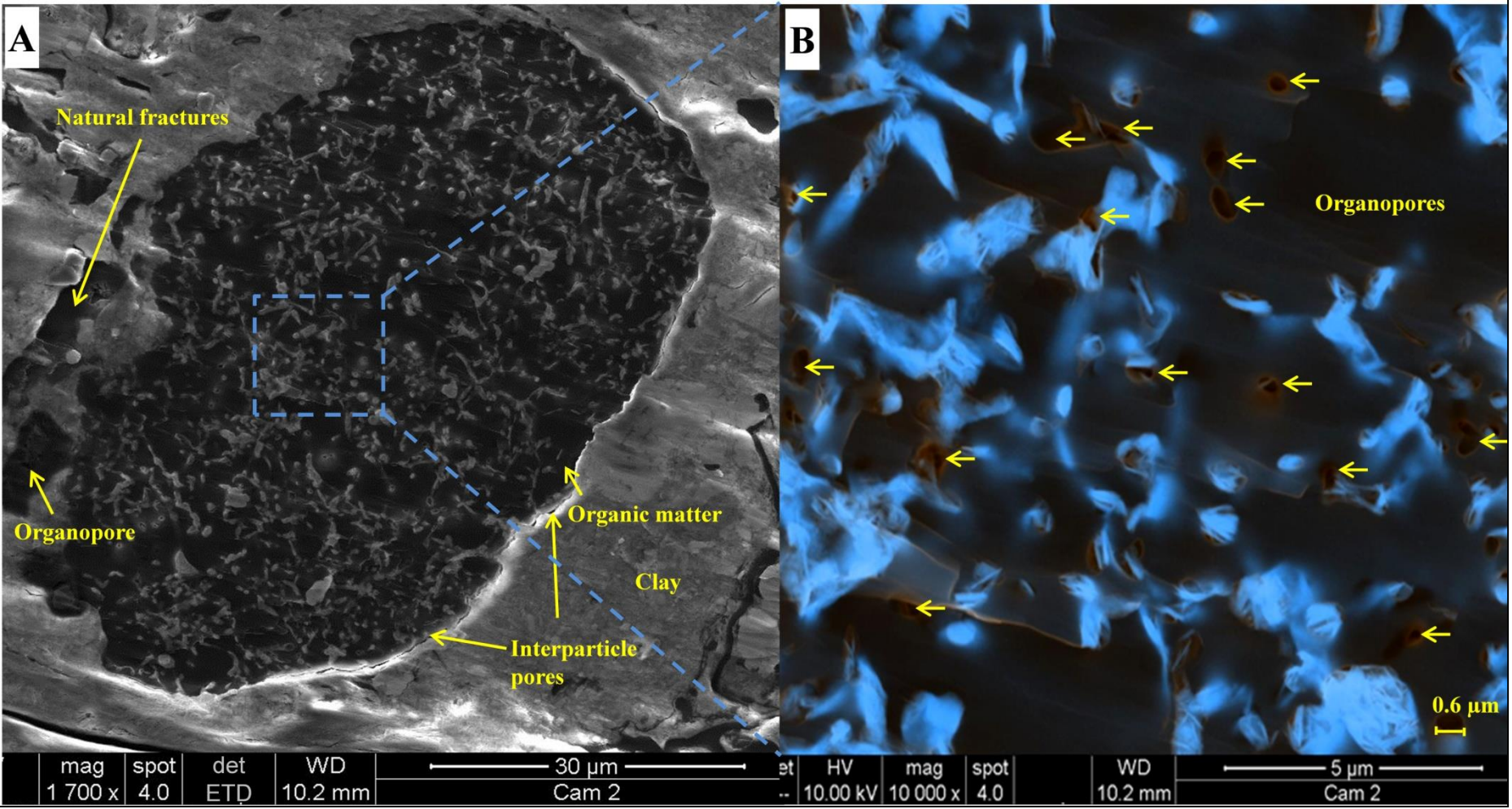



SEM image showing micro- and nano-porosity
det

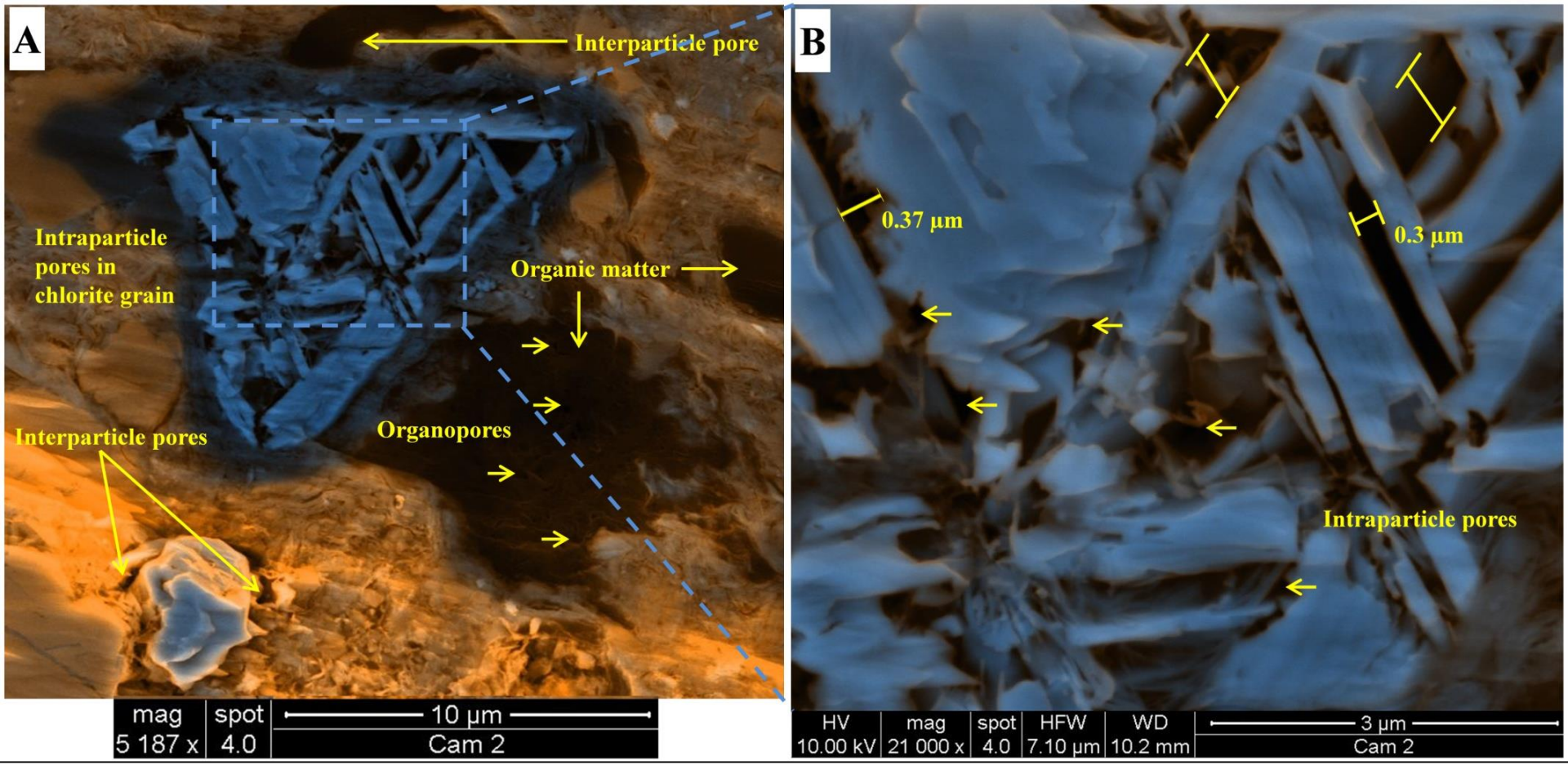
HV
10.00 kV
mag
4 000 x
spot
4.0
HFW
37.3 µm
WD
10.2 mm
10 µm
Cam 2



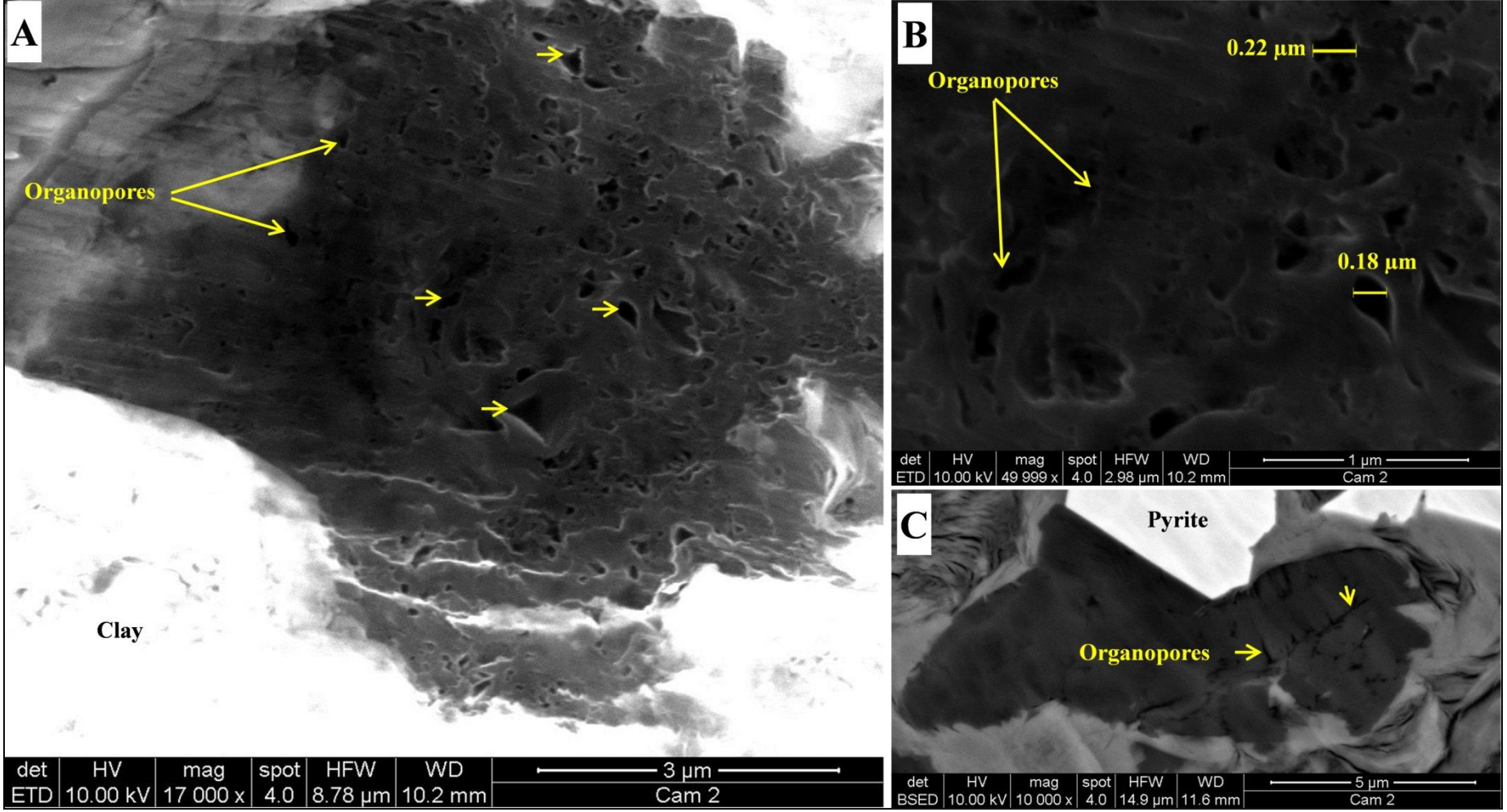
(A) Grain rim interparticle pores along rigid clay-size grain. Sub-rounded interparticle pores along clay particles and intraparticle pores on the rigid clay-size grain are also present. (B) Enlargement of blue-framed area in (A). Rounded and linear intraparticle pores of nanometer size.



Interparticle pores between organic matter and clay particles. Linear natural fractures and organopores are also present. (B) Enlargement of blue-framed area (organic matter) in (A). The Image shows numerous round-shaped organopores of nanometer size.

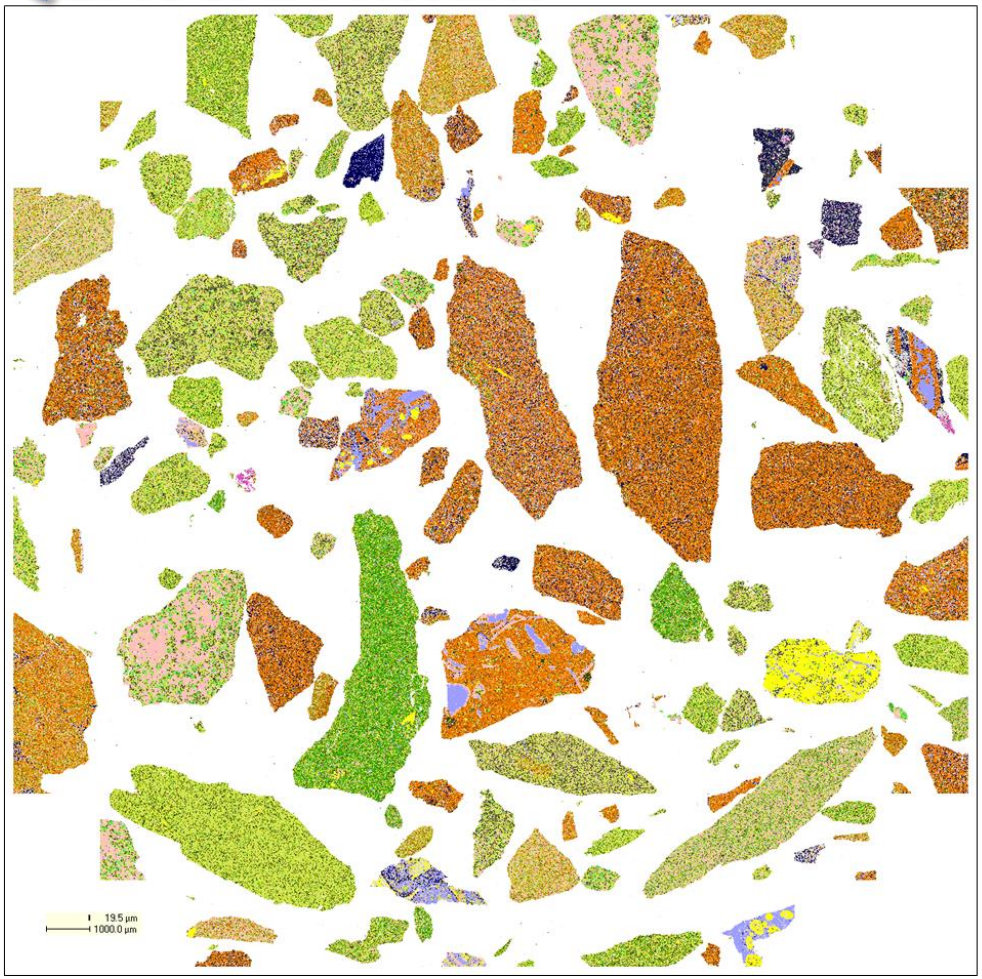


(A) The sample contains sheet-like intraparticle pores within chlorite grain. Interparticle and organopores are also present. (B) Enlargement of blue-framed area in (A). The image shows long and elongated intraparticle pores.



The FEG-SEM images (A, B & C) show organic matter hosted pores (organopores) of different shapes.

QEMSCAN Results

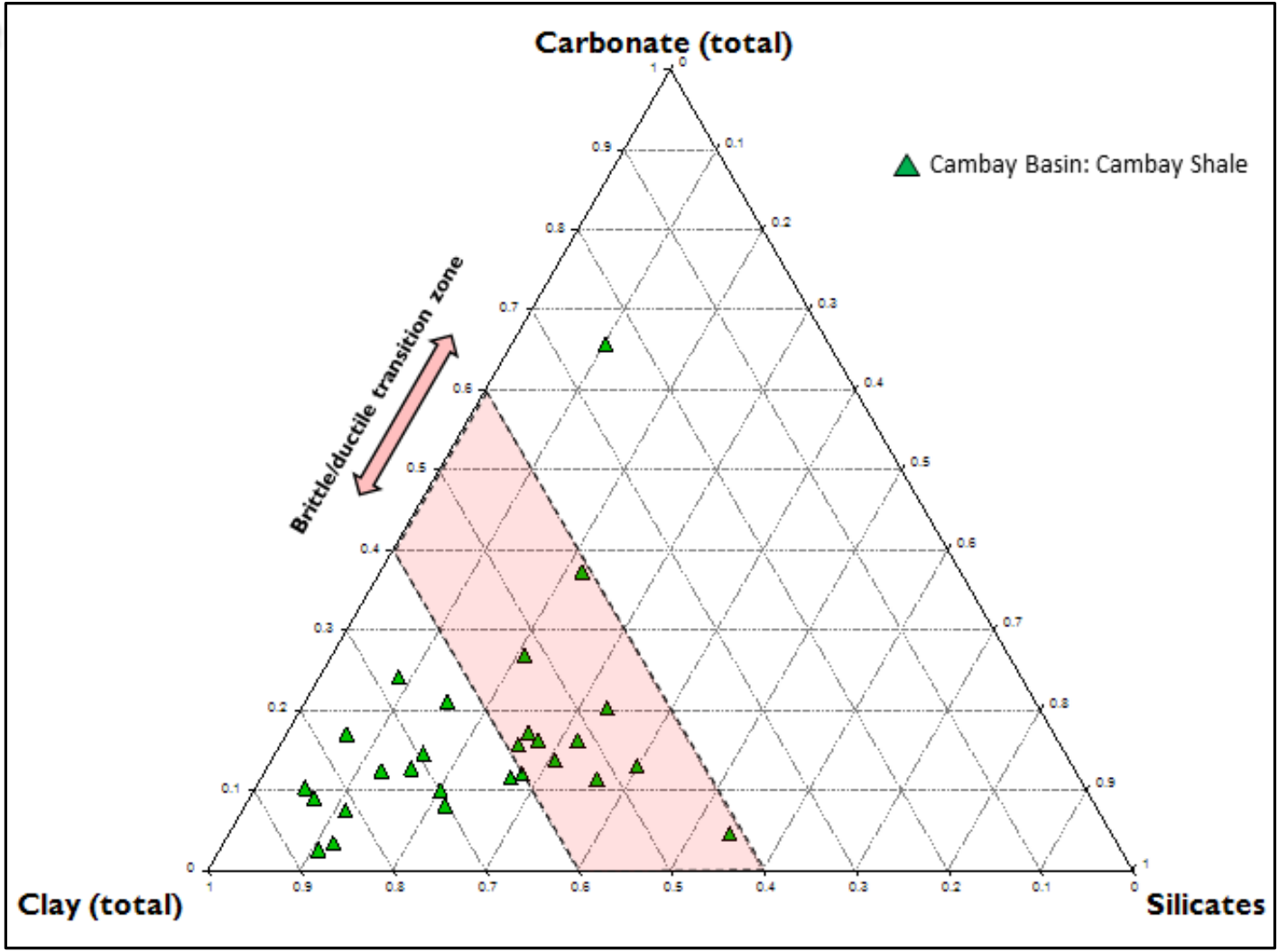


CAM 16

- Presence of Illite and Chlorite indicate alkaline (marine) environment
- Siderite suggest anoxic environment and the absence of sulphates
- Pyrite + Glauconite = Anoxia
- Some detrital input also seen

	Mineral Name	Area %
Marine Env. Anoxia	Chlorite	24.99
	Siderite	18.86
	Quartz	11.06
	Fe-oxides	7.30
	Particle Rims	6.71
	Other	5.01
	Illite	4.96
	Other Silicates	4.60
	Smectites	4.50
	Ankerite	3.88
Anoxia	Pyrite	2.34
	Calcite	2.20
	Glauconite	1.90
	Background	0.85

Cambay Shale
XRD Results



Summary

- Priority basin for *shale resources* prospectivity; established infrastructure
- Intracratonic rift basin; Shale thickness vary from 500 – 1500 m; deepens towards the south.
- High heat flow due to the igneous intrusion and the shallowness of the Moho.
- Generation in Eocene in South and in Mid. Miocene in North
- Geochemical analyses: Kerogen Type II & III; oil and gas window
- Well developed Intercrystalline intraparticle pores and organopores
- XRD and QEMSCAN: high clay content (40 – 85%).

Acknowledgements

We gratefully acknowledge the support of many individuals whose efforts and encouragement have paved the way for the incremental enrichment of knowledge presented here. Research funding and analytical support by Eni, EGI & NGRI are gratefully acknowledged.