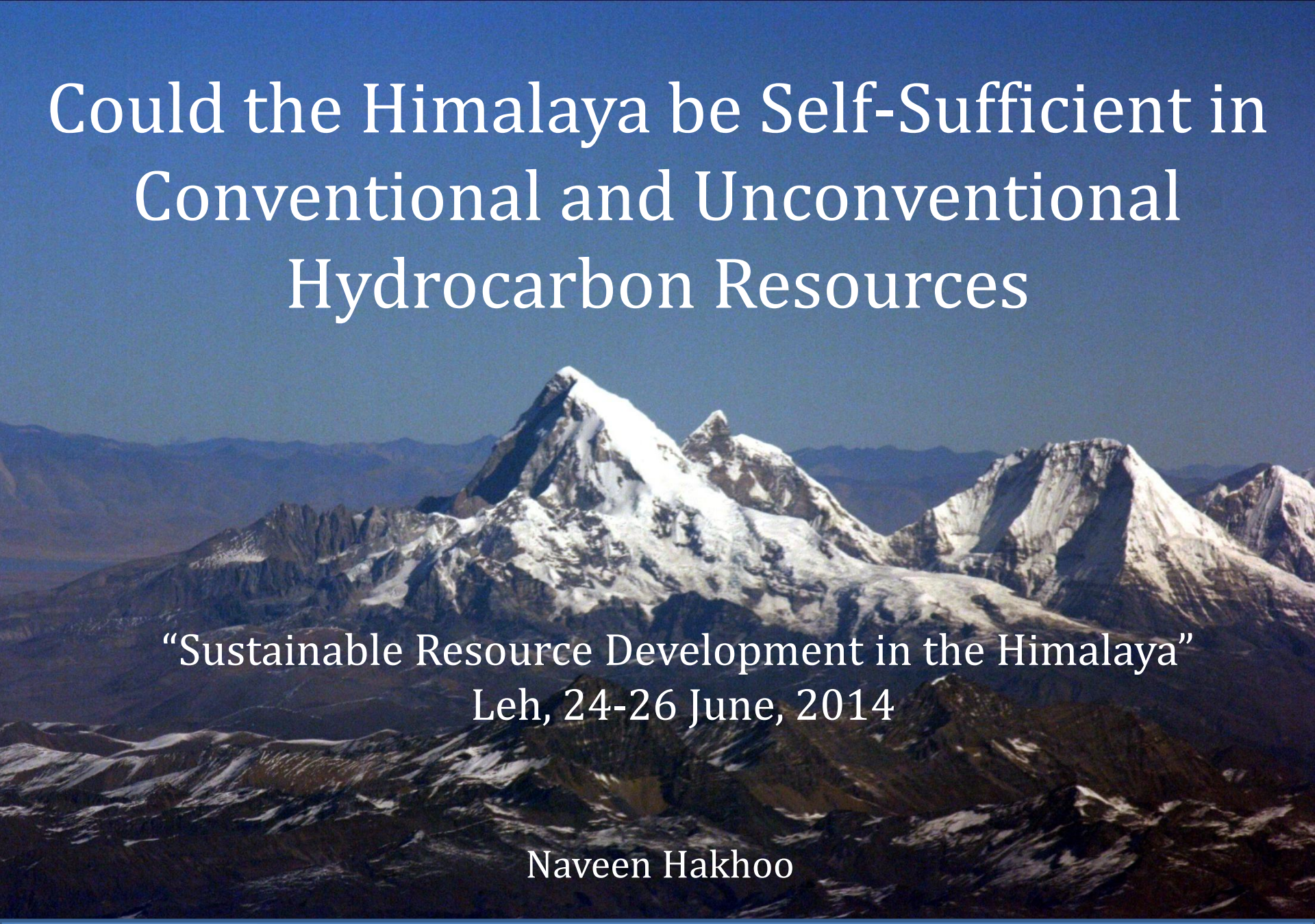
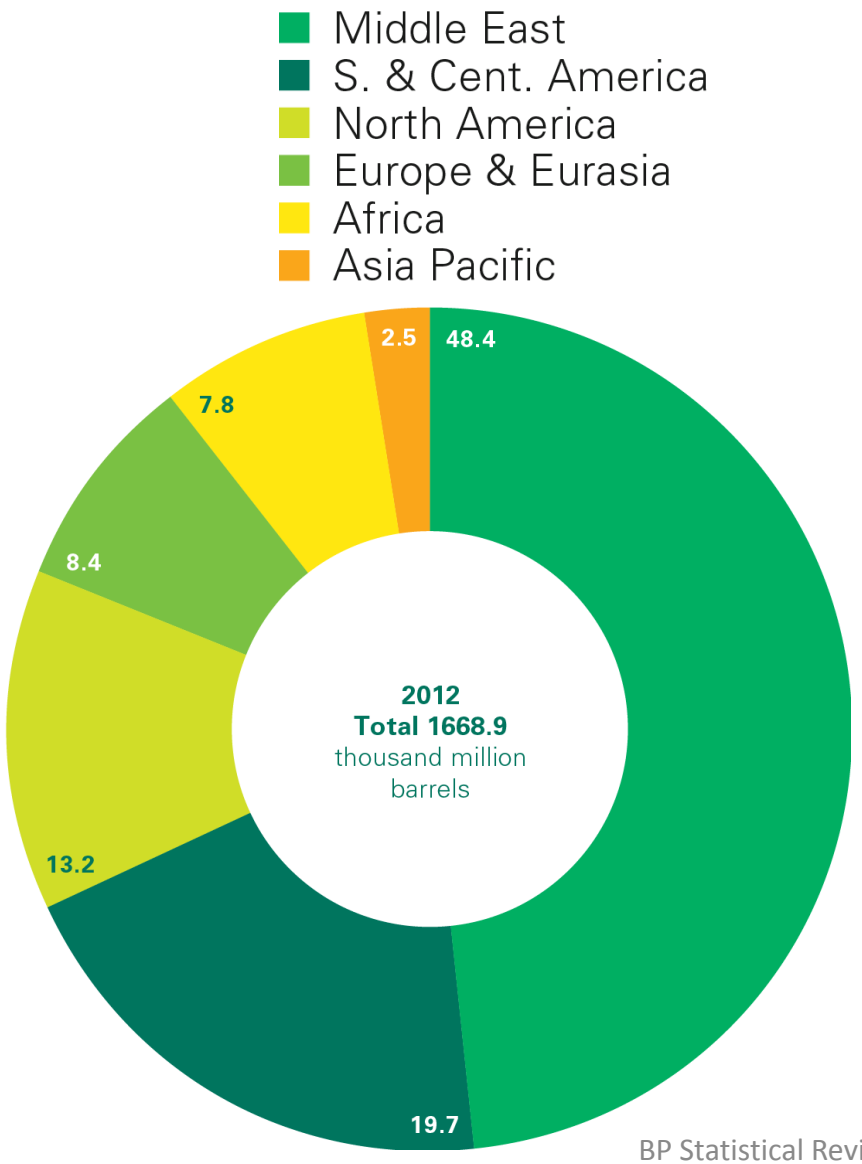
Could the Himalaya be Self-Sufficient in Conventional and Unconventional Hydrocarbon Resources

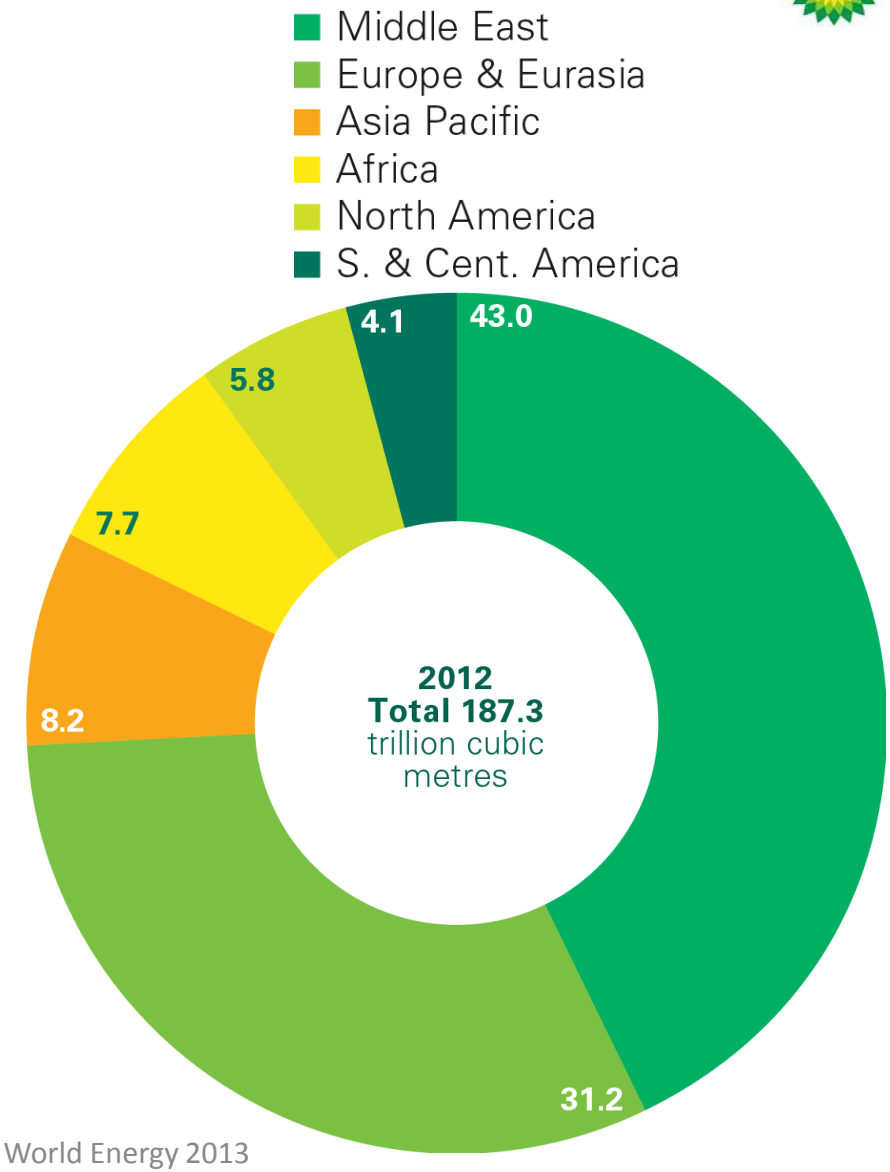


"Sustainable Resource Development in the Himalaya"
Leh, 24-26 June, 2014

Naveen Hakhoo

Distribution of proved oil and gas reserves in 2012 (Percentage)

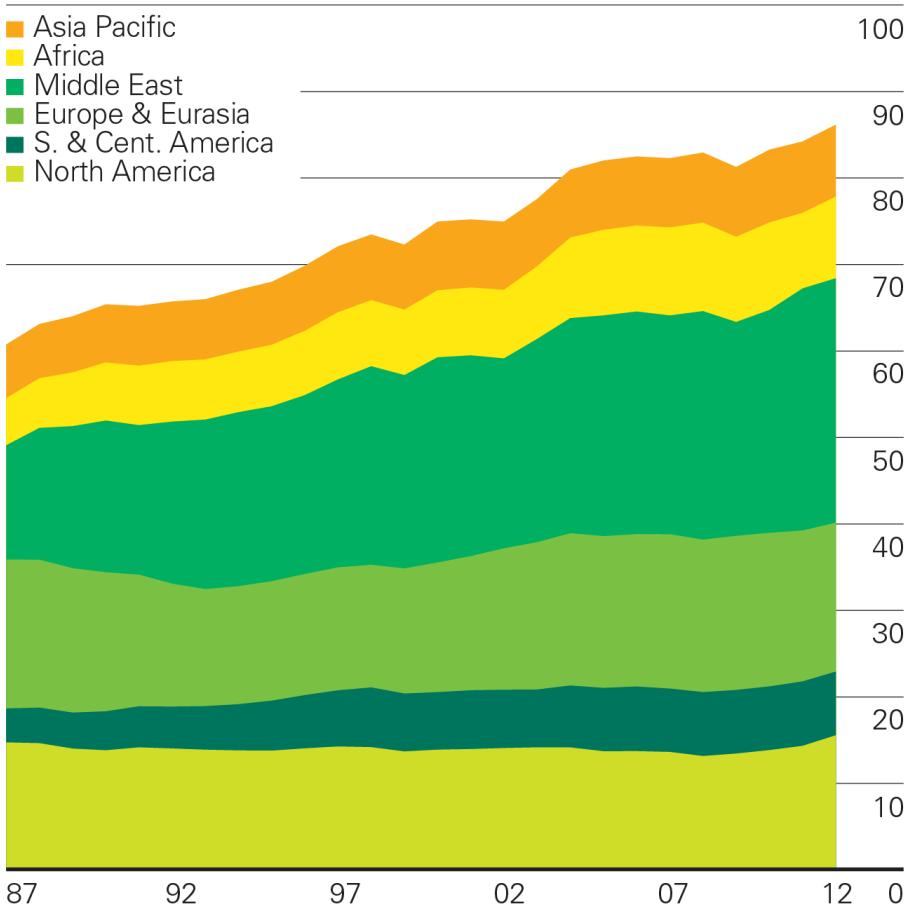




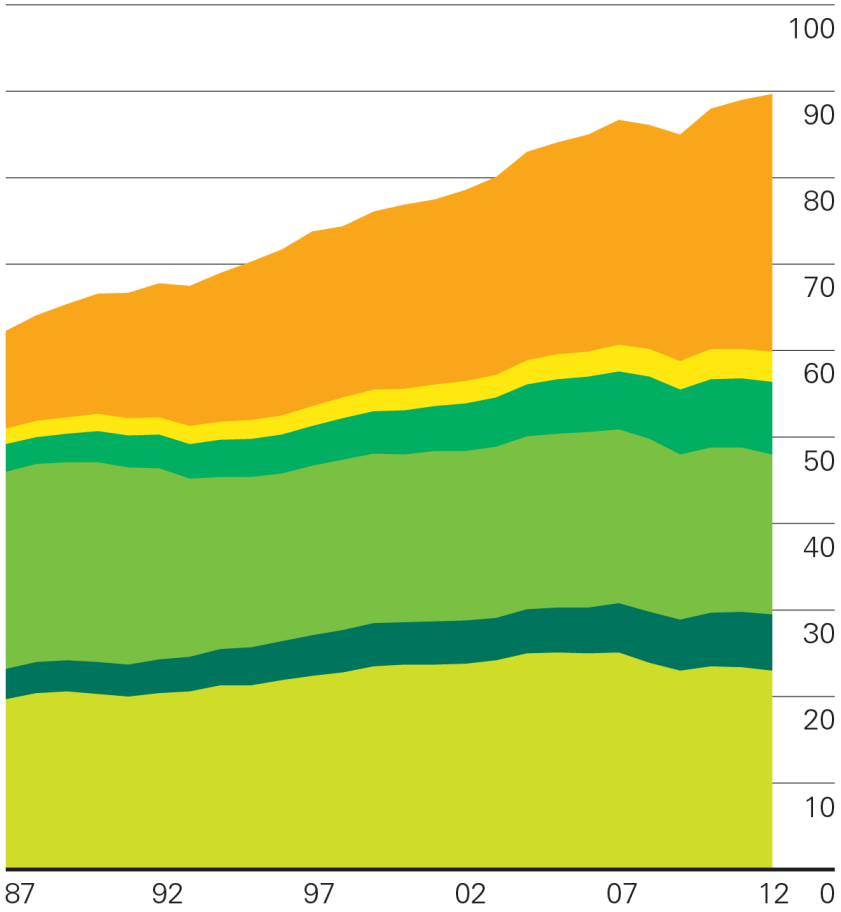
BP Statistical Review of World Energy 2013

Oil production/consumption by region
Million barrels daily

Production by region



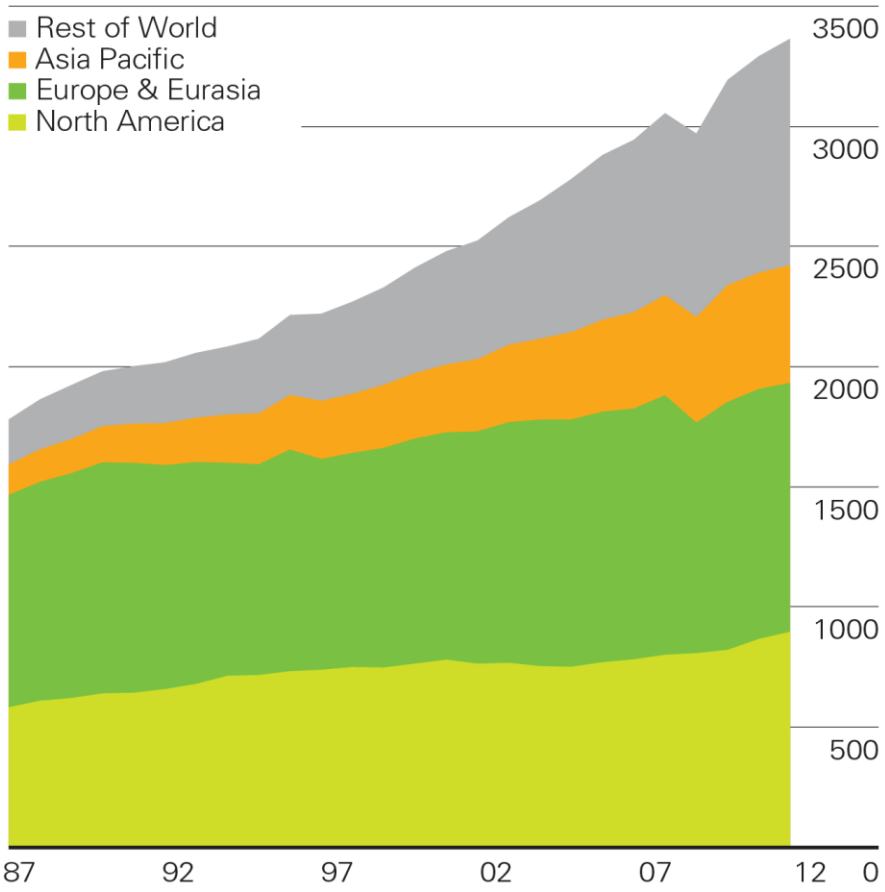
Consumption by region



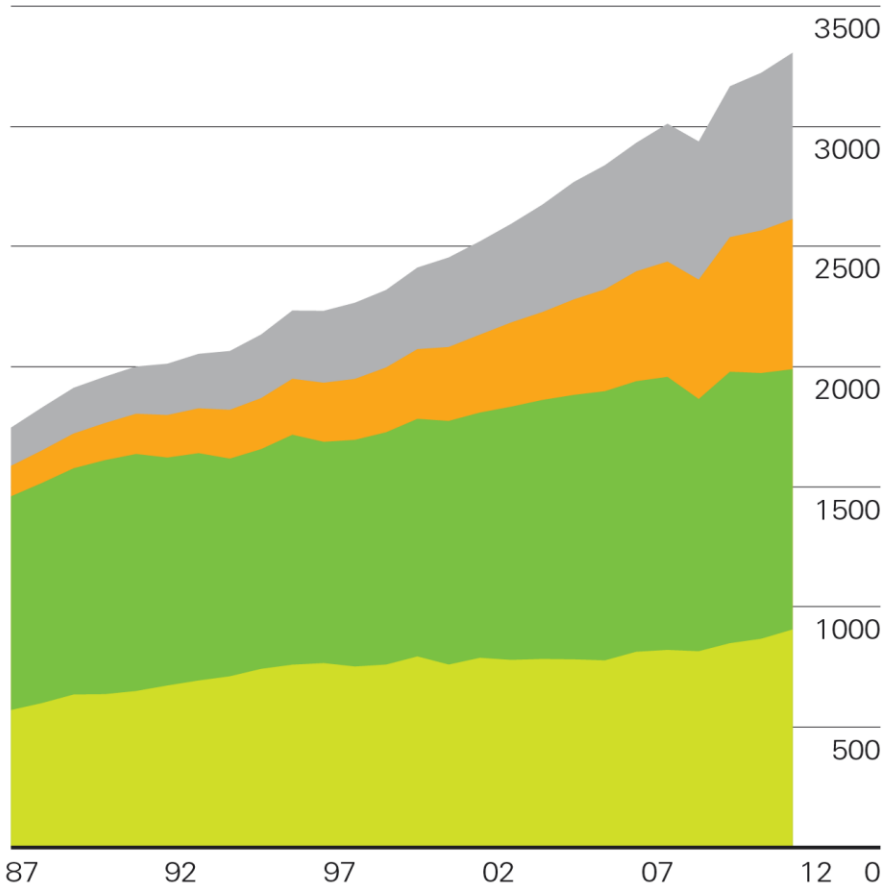
BP Statistical Review of World Energy 2013

Gas production/consumption by region
Billion cubic metres

Production by region

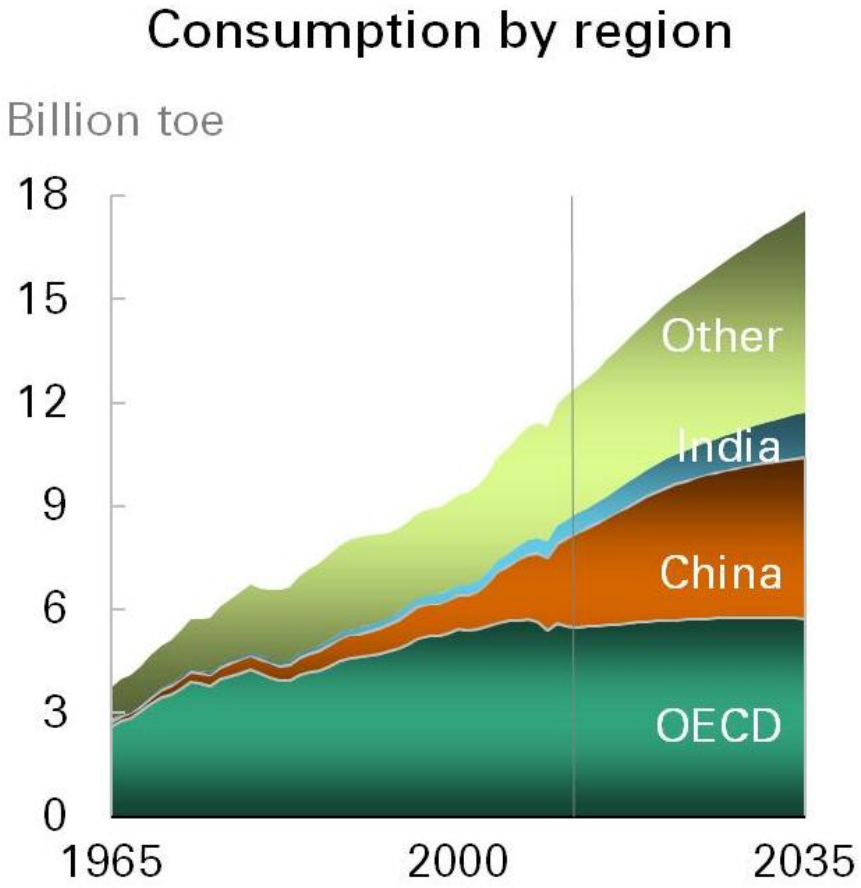


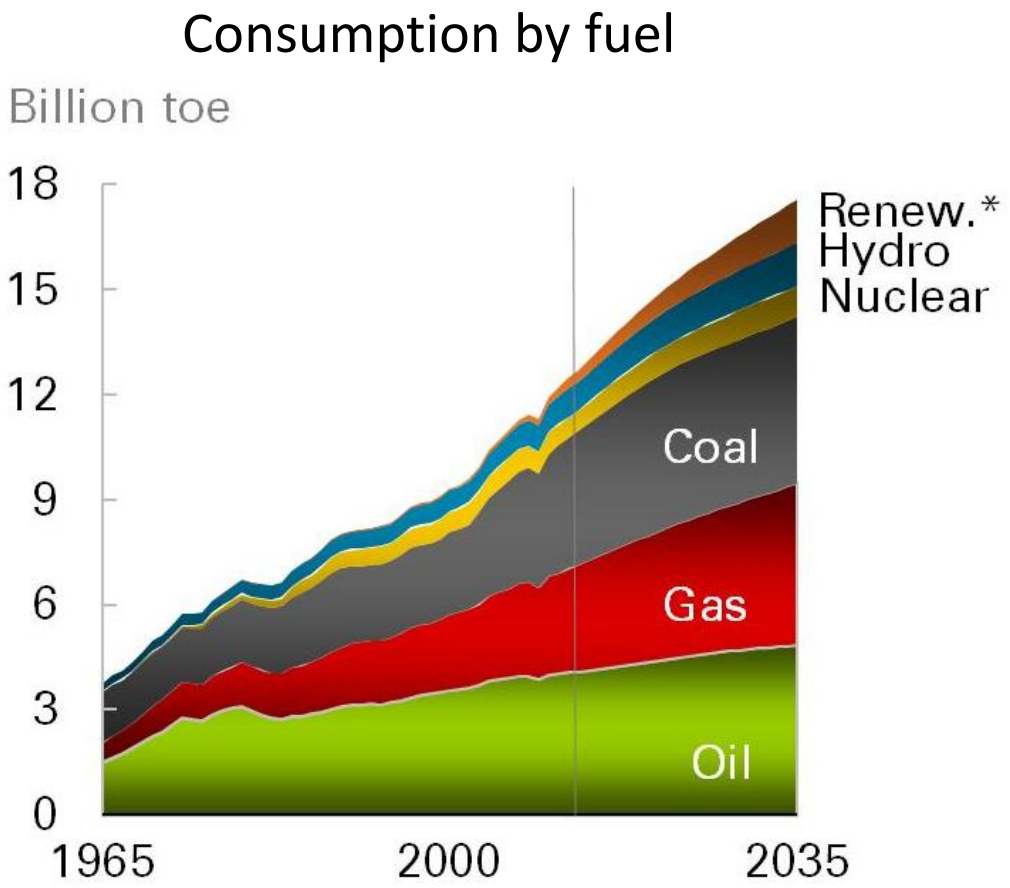
Consumption by region



BP Statistical Review of World Energy 2013

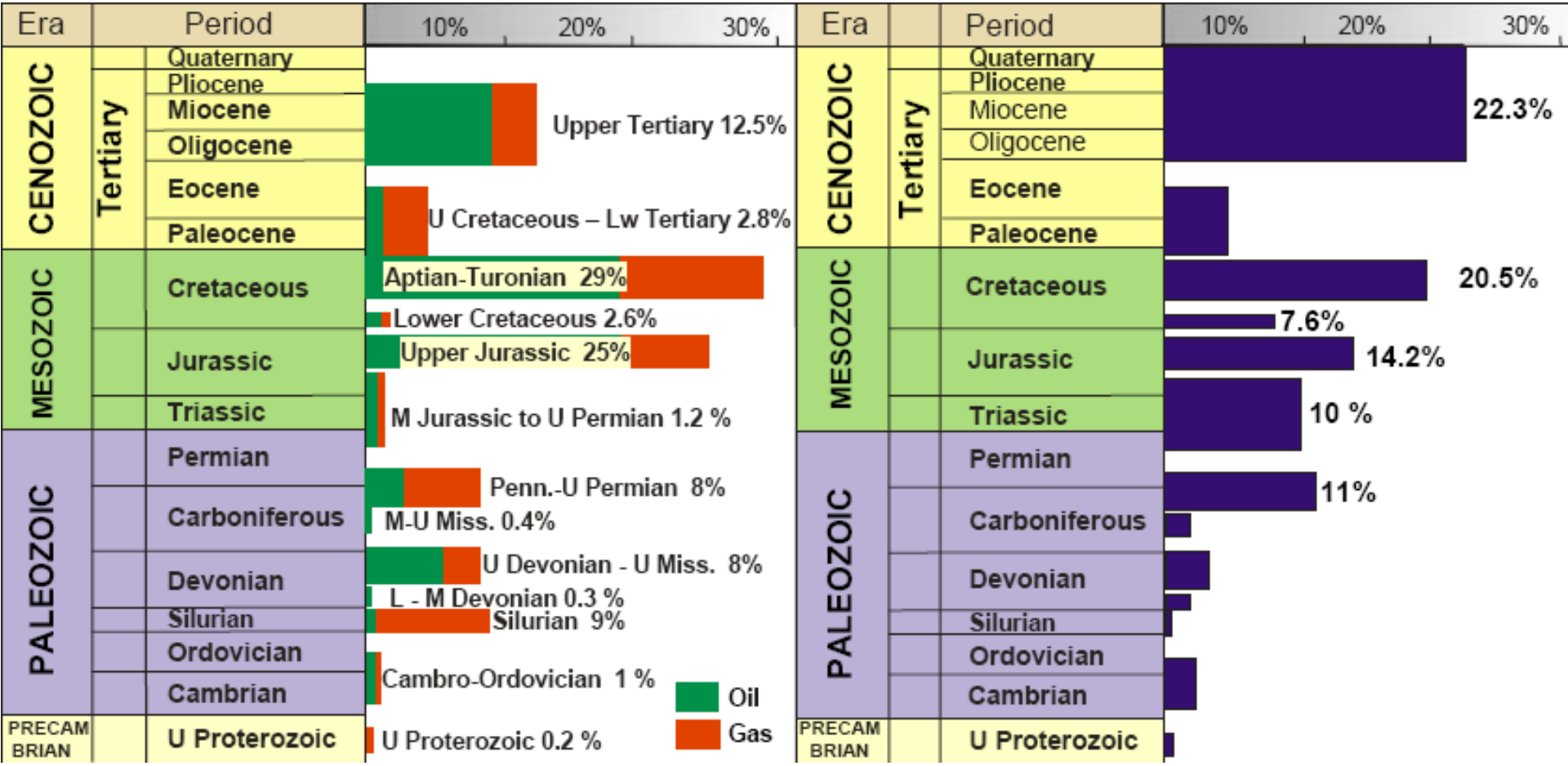
Primary Energy Consumption





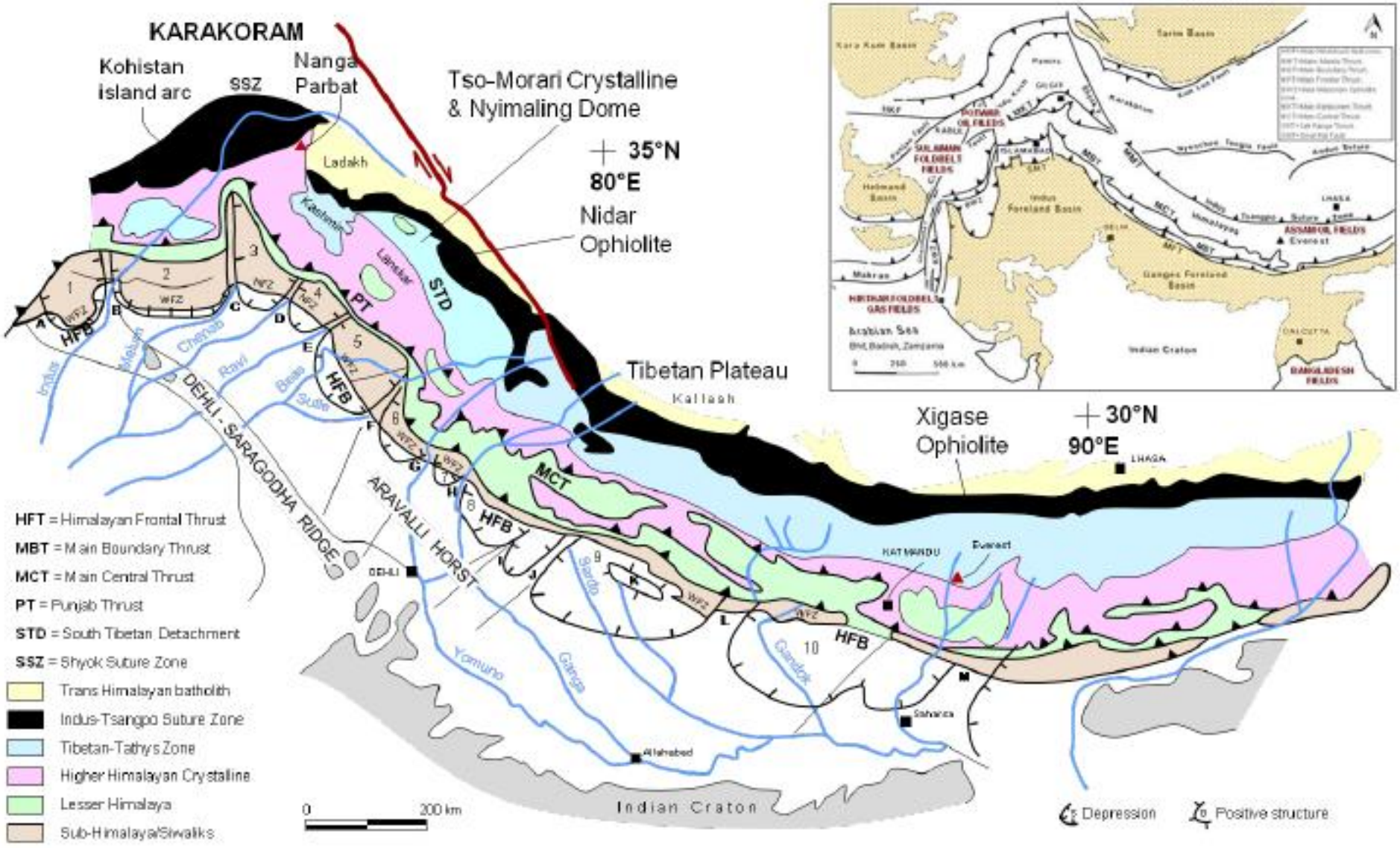
Energy Outlook 2035

Hydrocarbon Source and Reservoir Rocks through Geological Time



Kendall et al., AAPG Search and Discovery Article #40472 (2009)
Originally from Ulmashek and Klemm, 1990

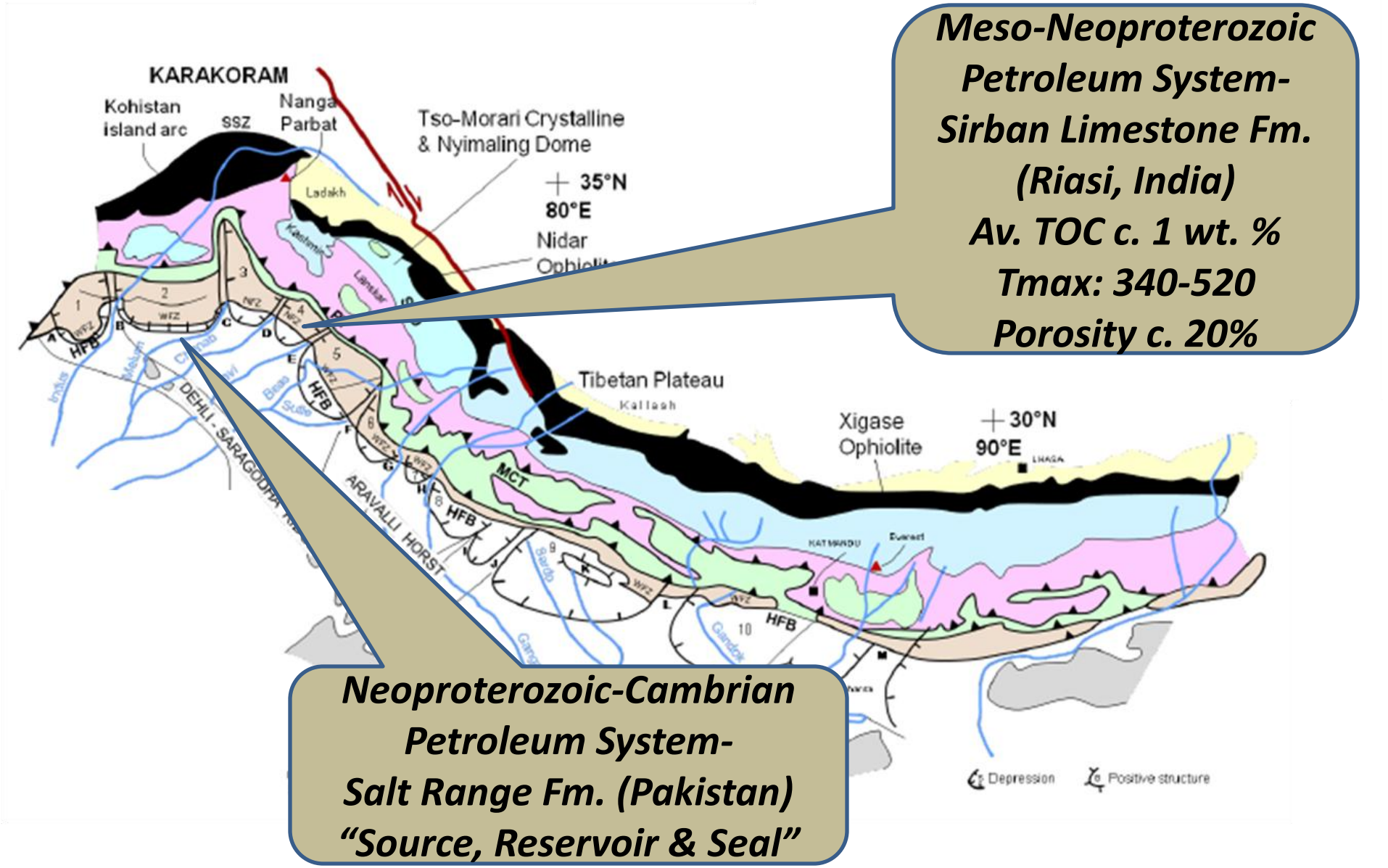
Distribution of Source and Reservoir Rocks



General geology and tectonics of the Himalayan arc and the Foreland Basin
(after Gupta and Gahalaut, 2012; Raiverman, 2013)

Craig et al., In Prep

Proterozoic Petroleum Systems



Meso-Neoproterozoic Petroleum System- Sirban Limestone Fm. (Riasi, India)
Av. TOC c. 1 wt. %
Tmax: 340-520
Porosity c. 20%

Neoproterozoic-Cambrian Petroleum System- Salt Range Fm. (Pakistan)
"Source, Reservoir & Seal"

Craig et al., In Prep

Palaeozoic Petroleum Systems

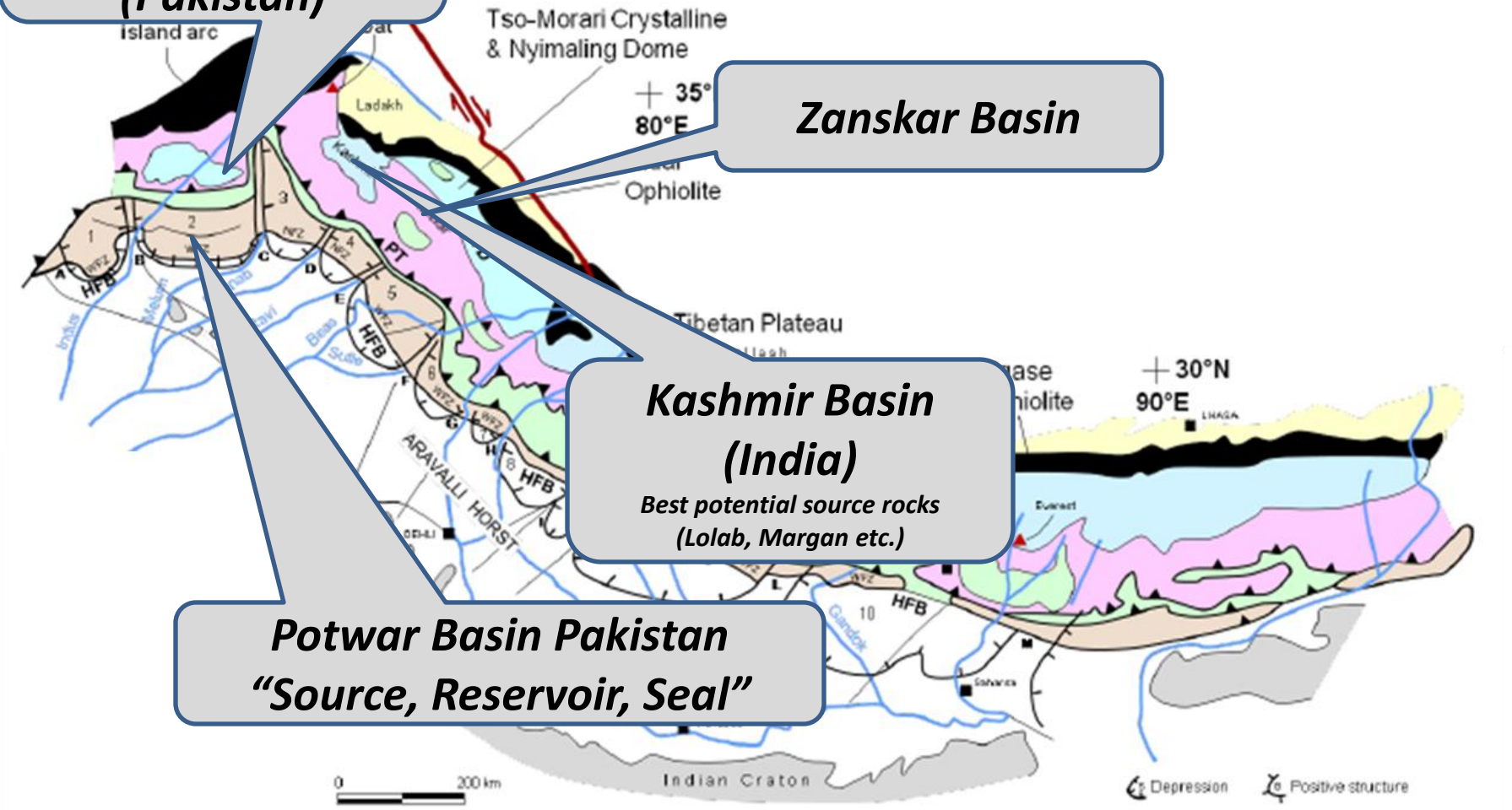
Eastern Peshawar Basin Inliers (Pakistan)

Zanskar Basin

Kashmir Basin (India)

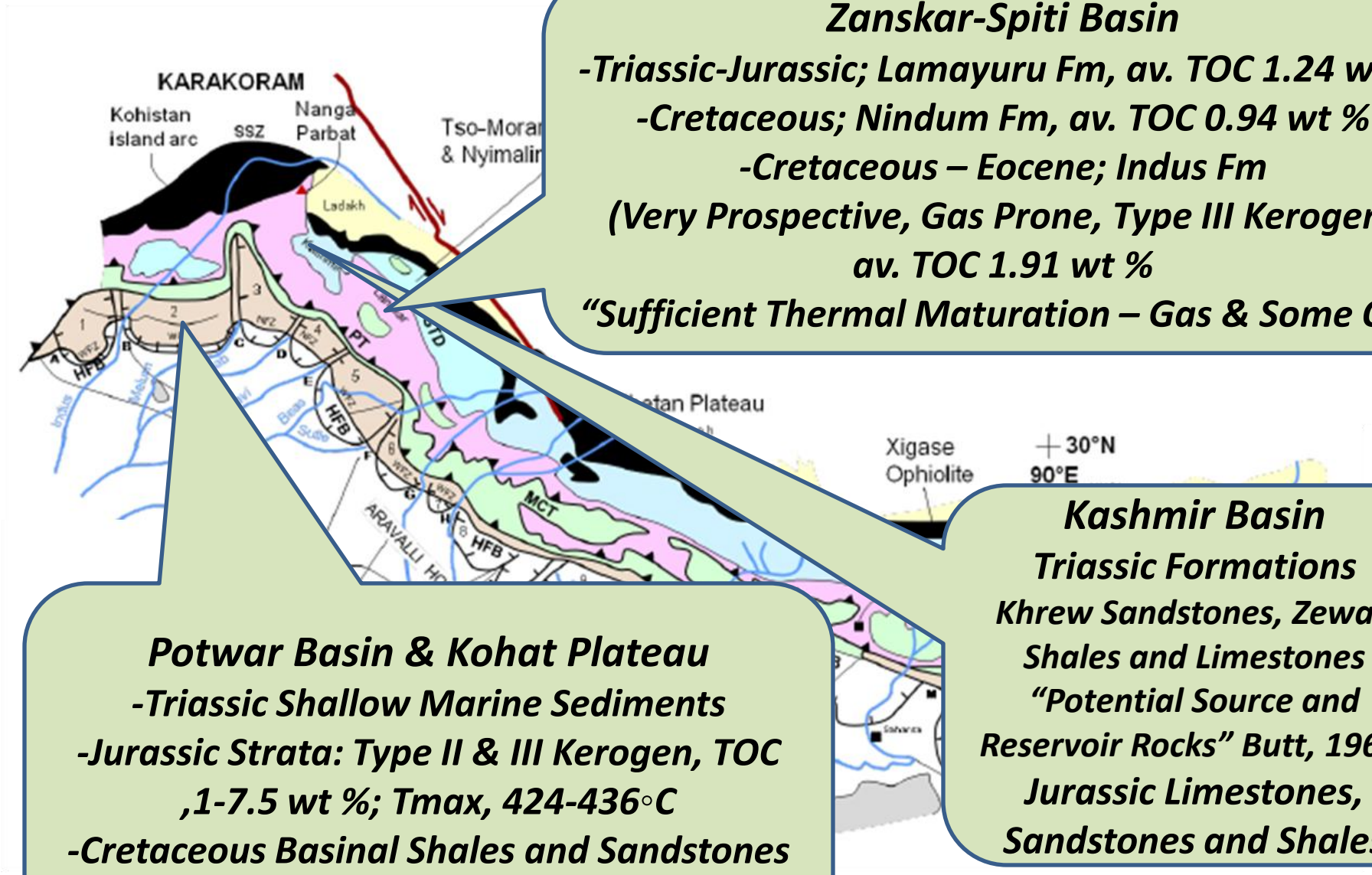
Best potential source rocks (Lolab, Margan etc.)

Potwar Basin Pakistan "Source, Reservoir, Seal"



Craig et al., In Prep

Mesozoic Petroleum Systems



Zanskar-Spiti Basin

-Triassic-Jurassic; Lamayuru Fm, av. TOC 1.24 wt %

-Cretaceous; Nindum Fm, av. TOC 0.94 wt %

-Cretaceous – Eocene; Indus Fm

(Very Prospective, Gas Prone, Type III Kerogen), av. TOC 1.91 wt %

"Sufficient Thermal Maturation – Gas & Some Oil"

Potwar Basin & Kohat Plateau

-Triassic Shallow Marine Sediments

-Jurassic Strata: Type II & III Kerogen, TOC ,1-7.5 wt %; Tmax, 424-436◦C

-Cretaceous Basinal Shales and Sandstones

- Production from Early Jurassic (Datta Fm)

Kashmir Basin

Triassic Formations

Khrew Sandstones, Zewan Shales and Limestones

"Potential Source and Reservoir Rocks" Butt, 1968.

Jurassic Limestones, Sandstones and Shales

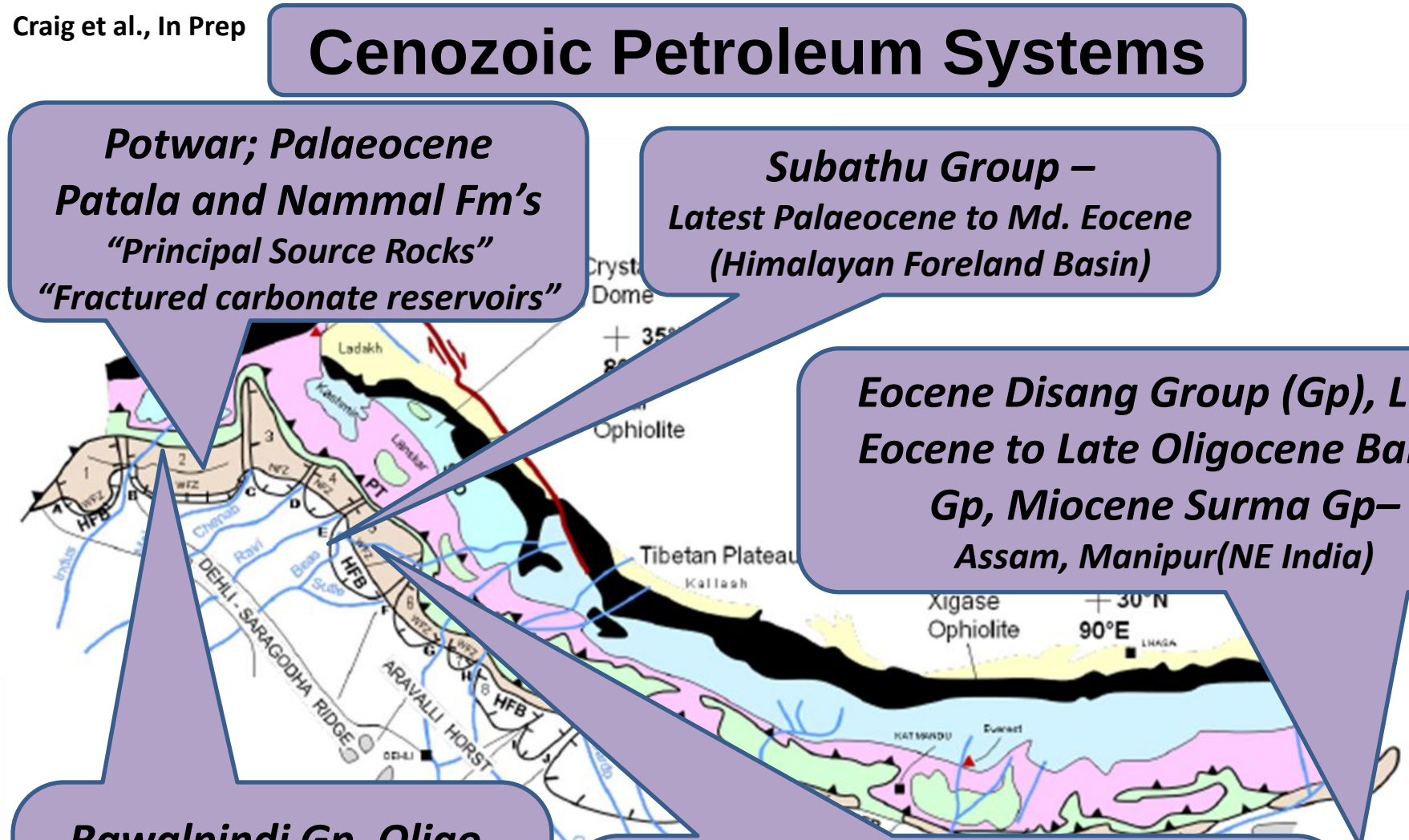
Craig et al., In Prep

Cenozoic Petroleum Systems

Potwar; Palaeocene Patala and Nammal Fm's
"Principal Source Rocks"
"Fractured carbonate reservoirs"

Subathu Group –
Latest Palaeocene to Md. Eocene
(Himalayan Foreland Basin)

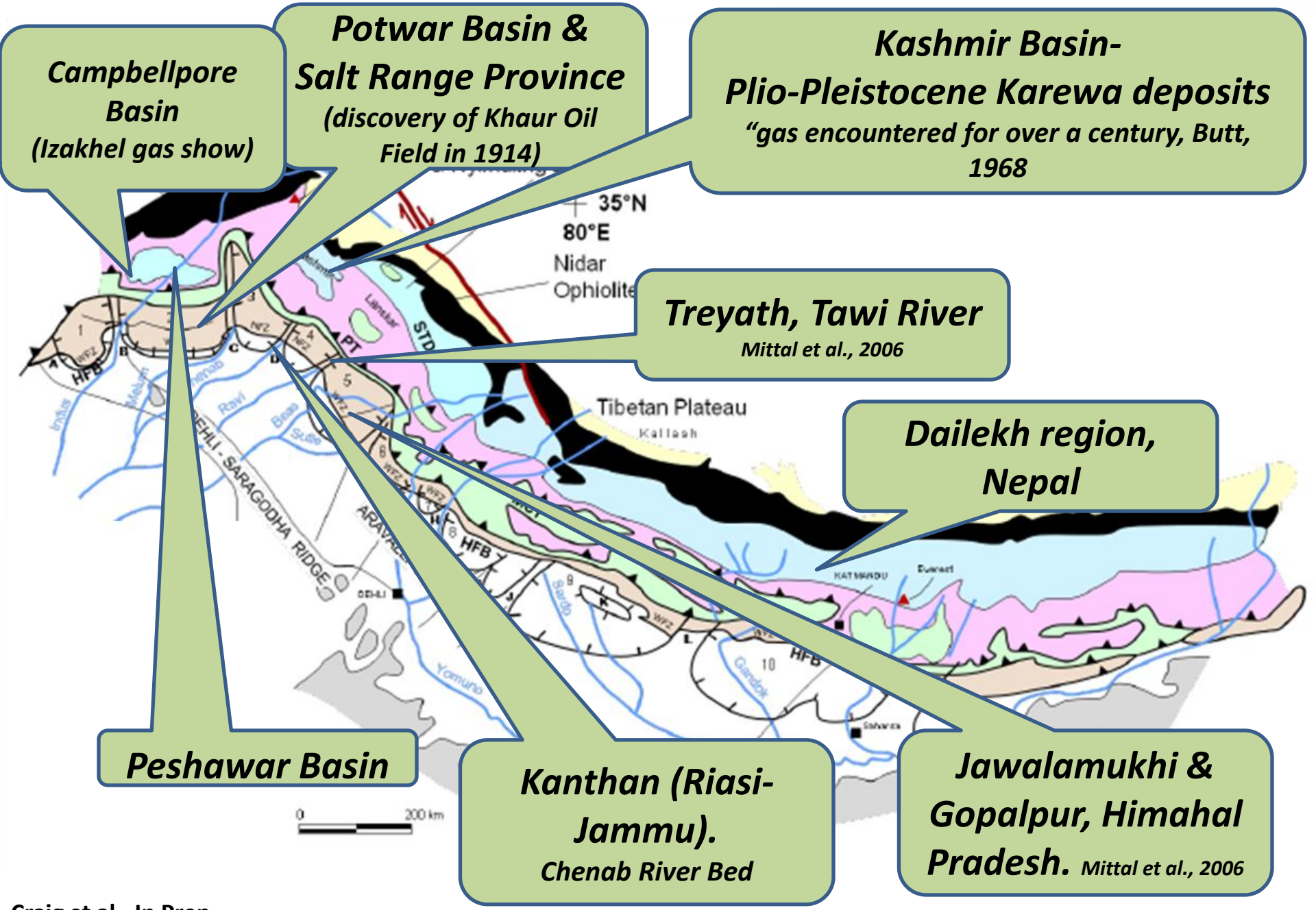
Eocene Disang Group (Gp), Late Eocene to Late Oligocene Barail Gp, Miocene Surma Gp–
Assam, Manipur(NE India)



Rawalpindi Gp, Oligo-Miocene of Pakistan
Murree Fm (Sandstones and Shales), youngest oil producing horizon

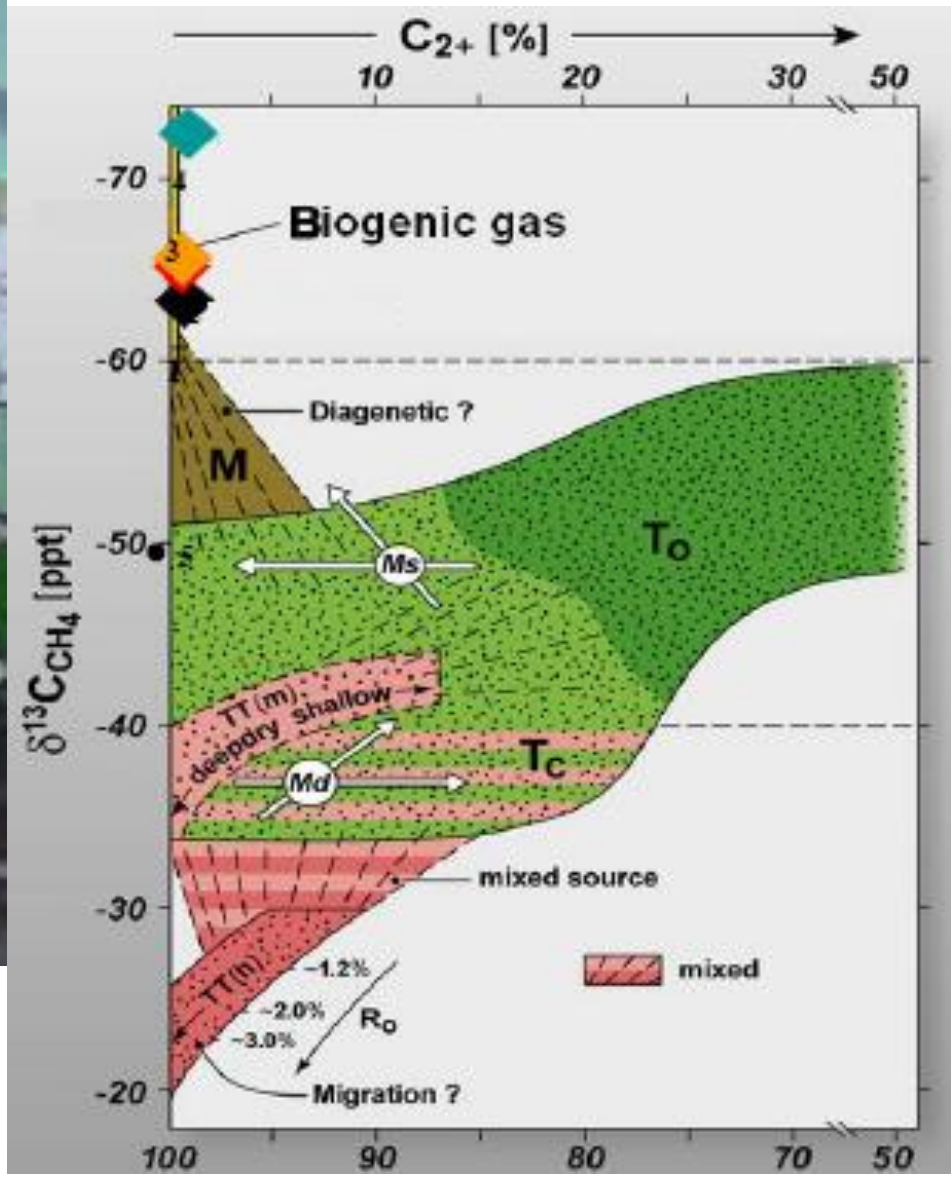
Dharamshala Fm.
(Murree, Dagshai & Kasauli
Oligocene to Lwr. Miocene
-VRo, 0.49%; Tmax, 425-441◦C; TAI, 2.5-2.75
"Oil Generation Window, beginning 10 Ma"

Oil and Gas Seeps; Main Drivers for the Early Exploration



Craig et al., In Prep

Households in Sadr-E-Kot (Sopore, Kashmir, India) use gas encountered in the Karewa Formation for Cooking



Isotopic Characterization of Kashmir Gas Occurrences

Craig et al., In Prep

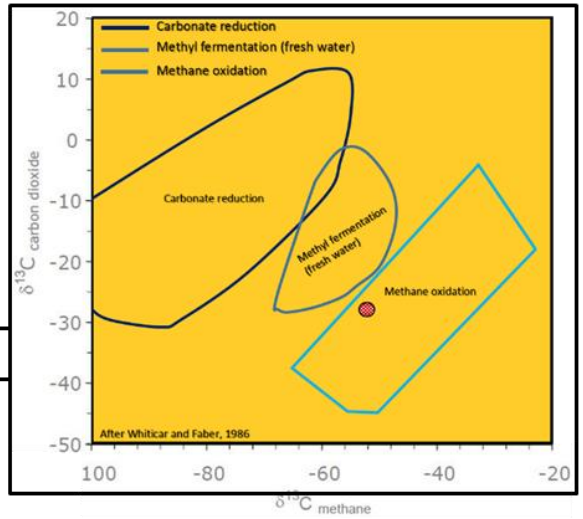
Gas Seep Geochemistry (Bulk chemical & isotopic composition)

eni & NGRI

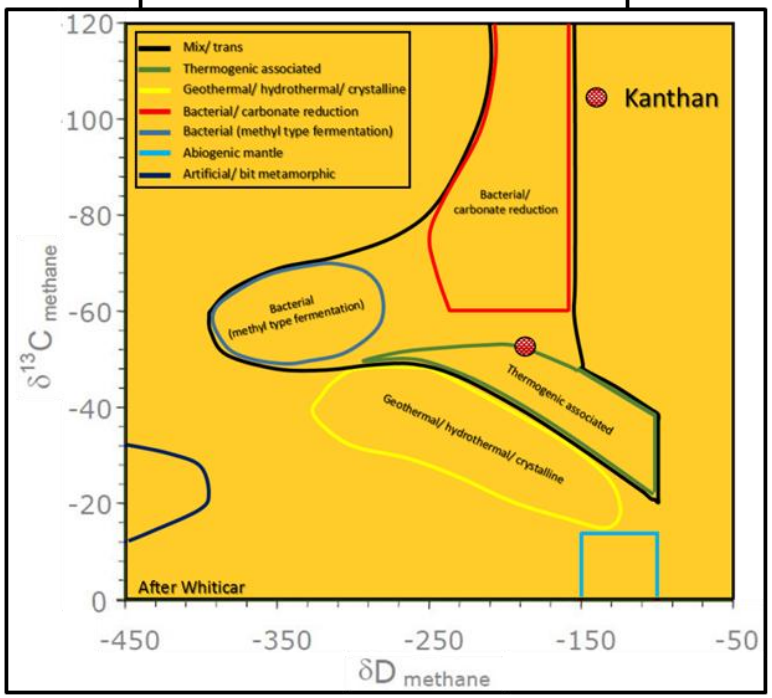
Sample	%CH_4	%CO_2	%N_2	$\delta^{13}C$ CH_4	δ D CH_4	$\delta^{13}C$ CO_2
Kanthan I	16.2	0.6	83.2	-51.46	-182.0	-24.9

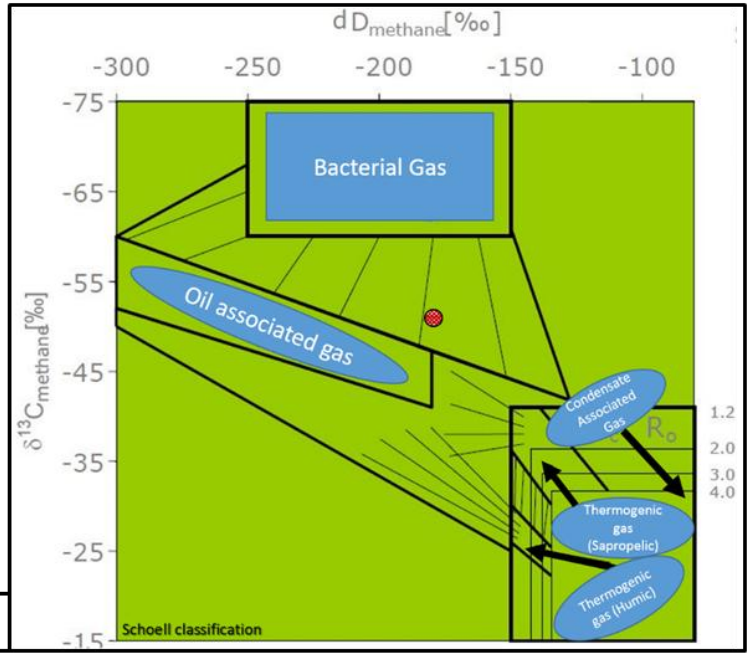
Source	Origin	Results
Subathu? (Shallow source)	Mixed (Thermo+Bio)	CH_4 enriched (Dry) Gas

Geochemical characterization CO_2



Geochemical characterization CH_4

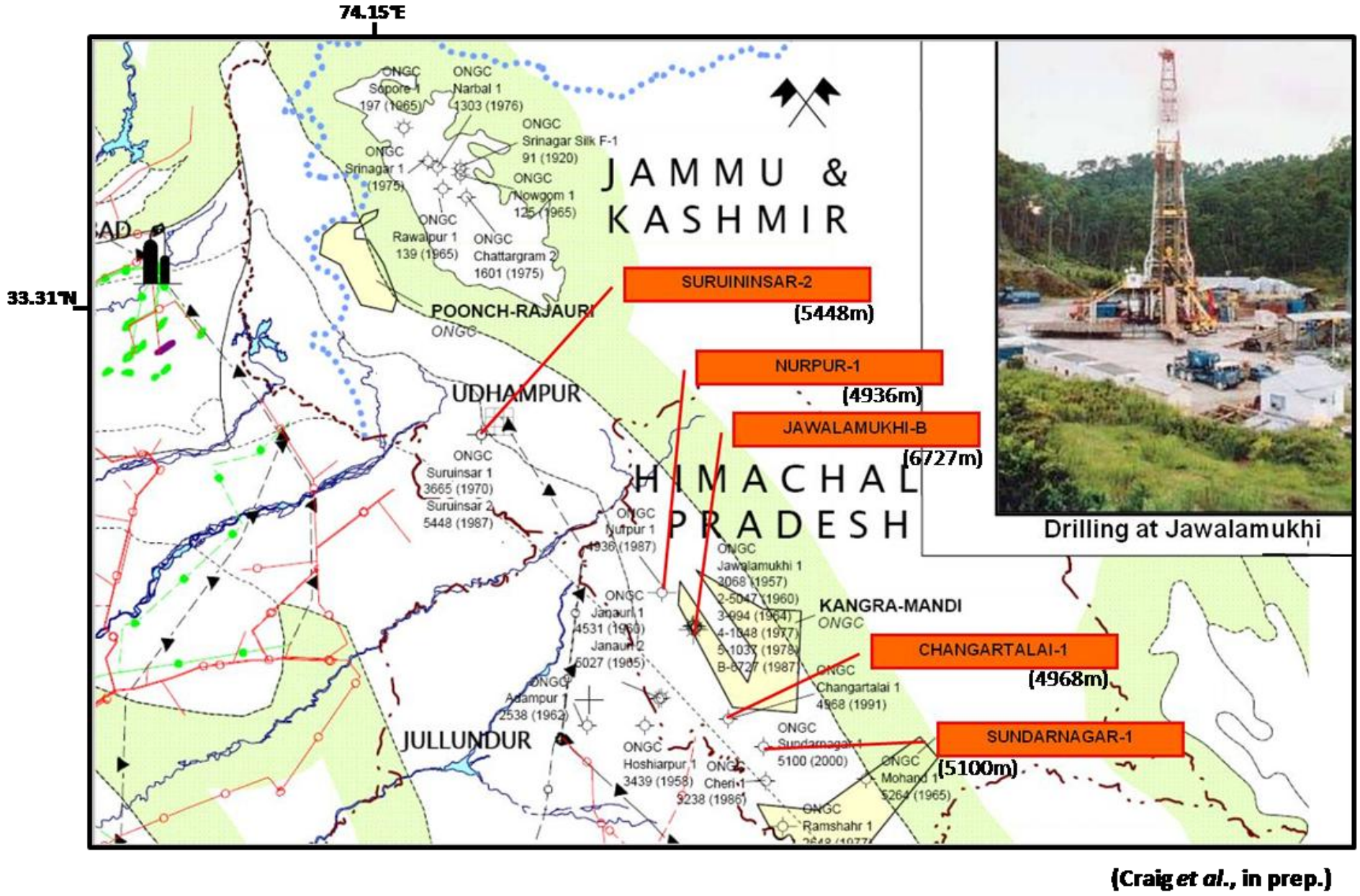




Geochemical characterization, CH_4 origin

Details of Exploration in NW Himalaya (Craig *et al.*, in prep.)	
Operator/ Company	Oil and Natural Gas Corporation Limited (ONGC)
Wells Drilled	34
1950-1960	2
1960-1970	10
1970-1980	5
1980-1990	10
1990-2000	4
2000-2010	3
Oil and Gas Shows	9 wells only
Maximum depth penetrated	6727m, Jawalamukhi
Subathu Group not penetrated in any of the wells	

Wells drilled in the NW Himalaya, India

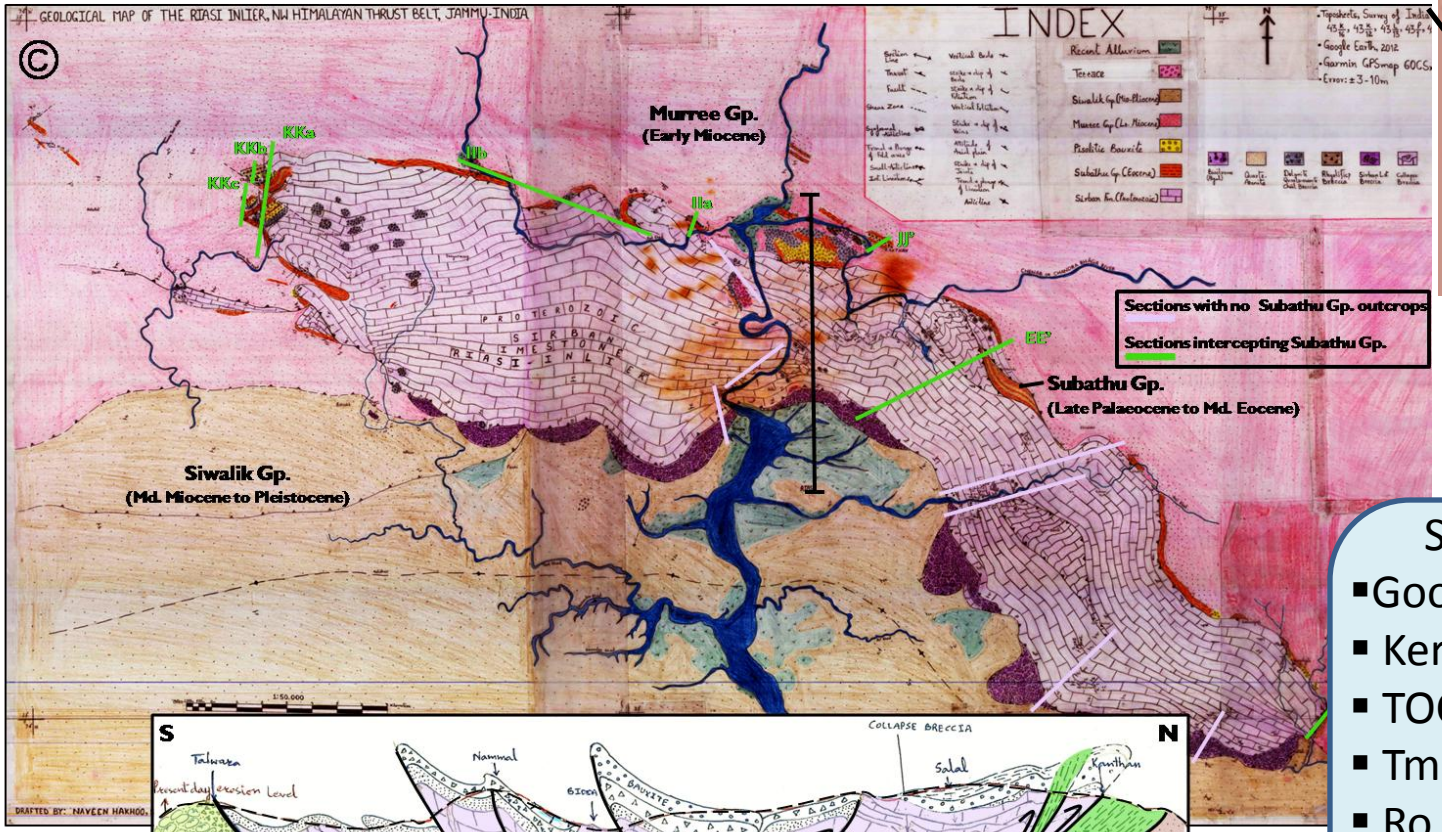


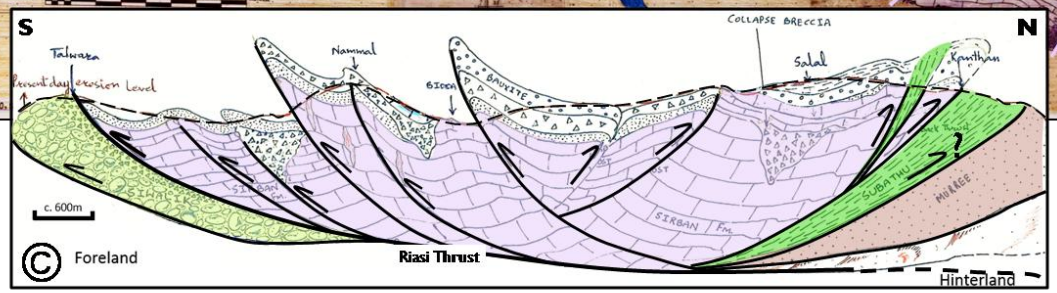
Drilling at Jawalamukhi

(Craig *et al.*, in prep.)

Research has focused on Neoproterozoic and Cenozoic (Eocene), Conventional (True and Hybrid) and Unconventional Petroleum Systems in the Himalayan Foreland Basin- Frontal Fold Thrust Belt.

Neoproterozoic Sirban Limestone Formation and Subathu Group





Schematic cross-section through the central part of the Riasi Inlier

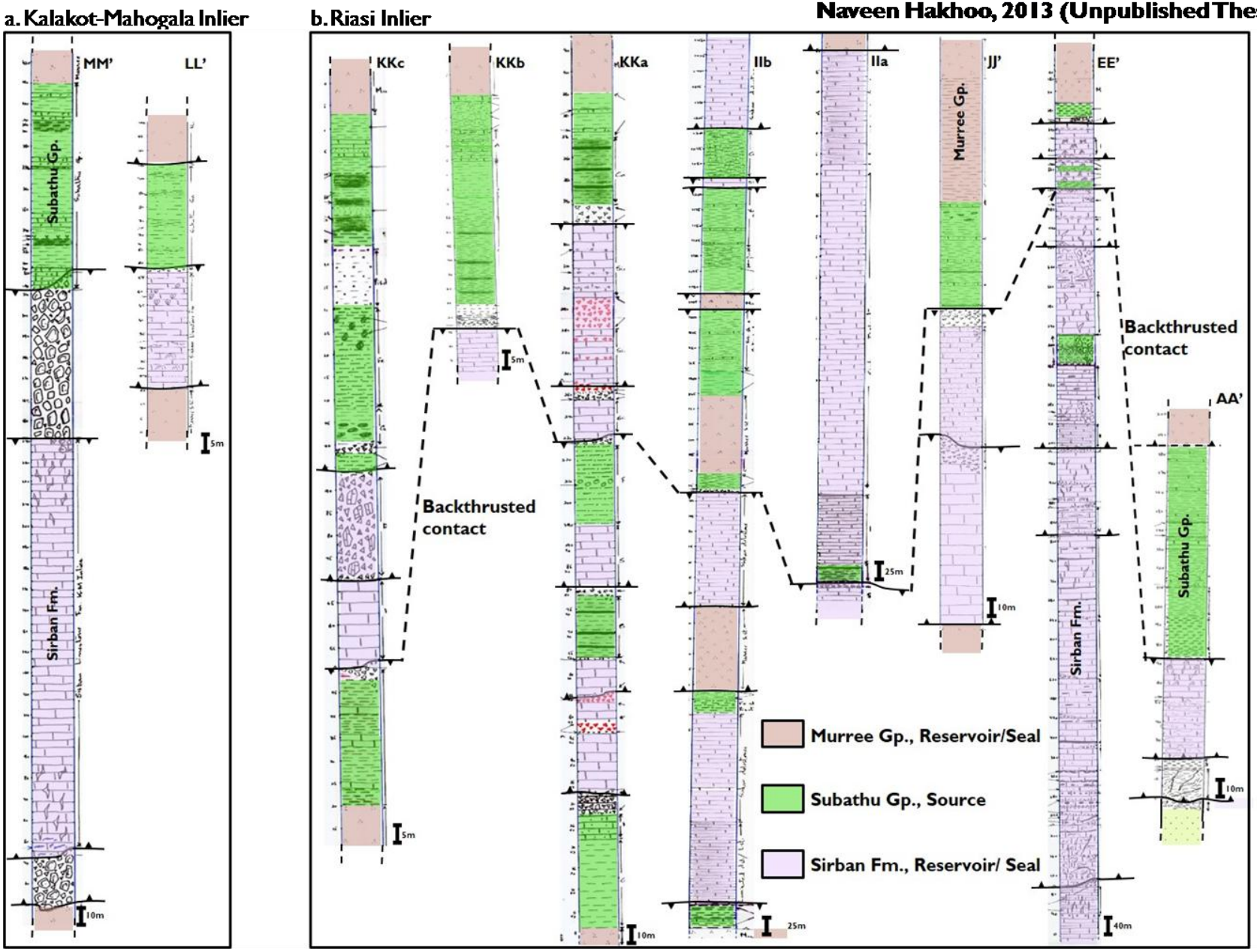
Naveen Hakhoo, 2013 (Unpublished Thesi

Subathu Gp Shales

- Good source rock quality
- Kerogen Type II & III
- TOC, 4-5%
- Tmax, 480-520◦C
- Ro, 1.41
- Silica rich (Fracable)
- With nano-porosity

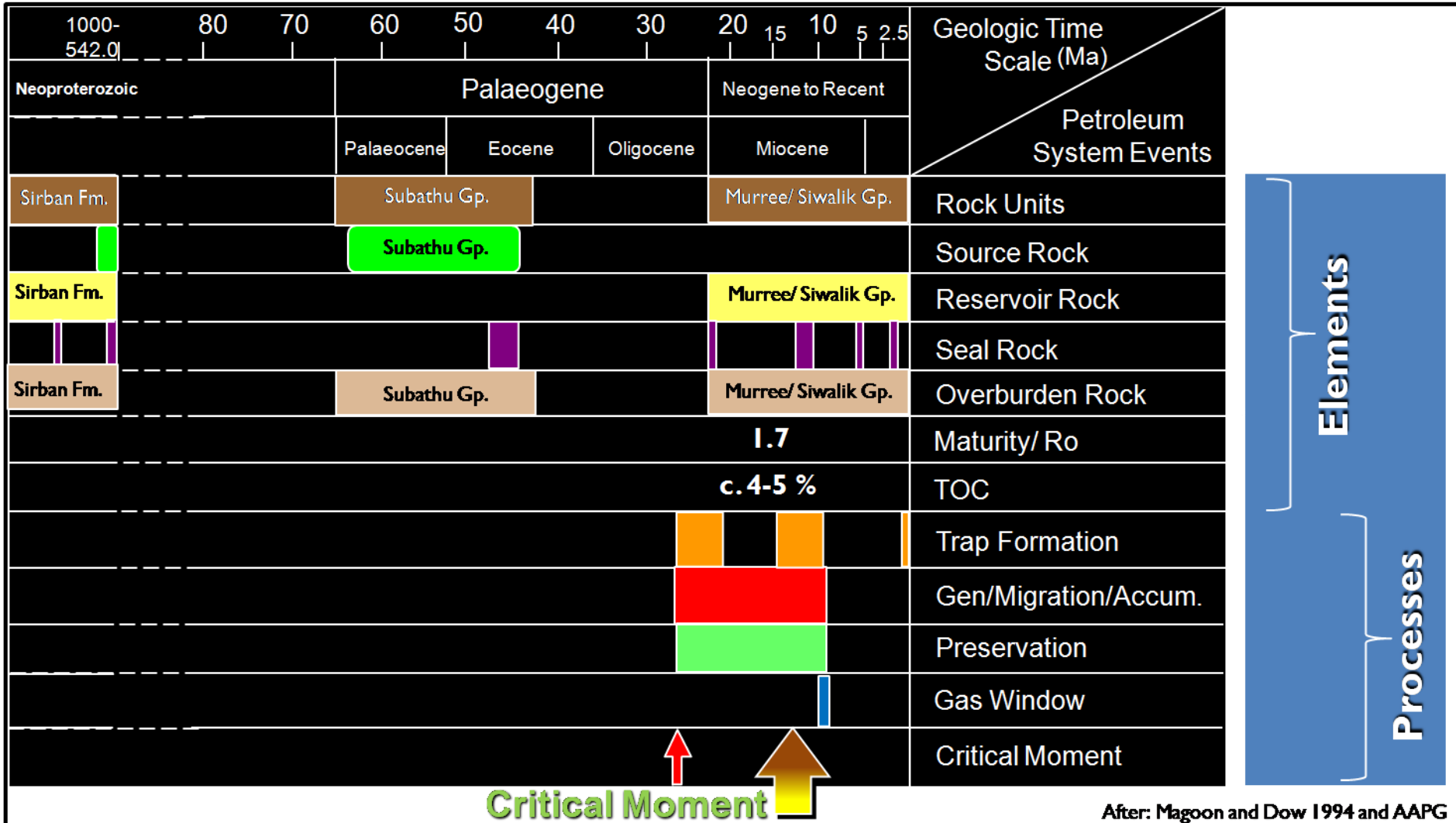
Tectono-stratigraphic logs, Sirban Limestone inliers (a & b), Sub-Himalayan Foreland Basin, India

Naveen Hakhoo, 2013 (Unpublished Thesis)



Petroleum System Events Chart

Timing of Elements and Processes In the Himalayan Foreland Basin and FTB

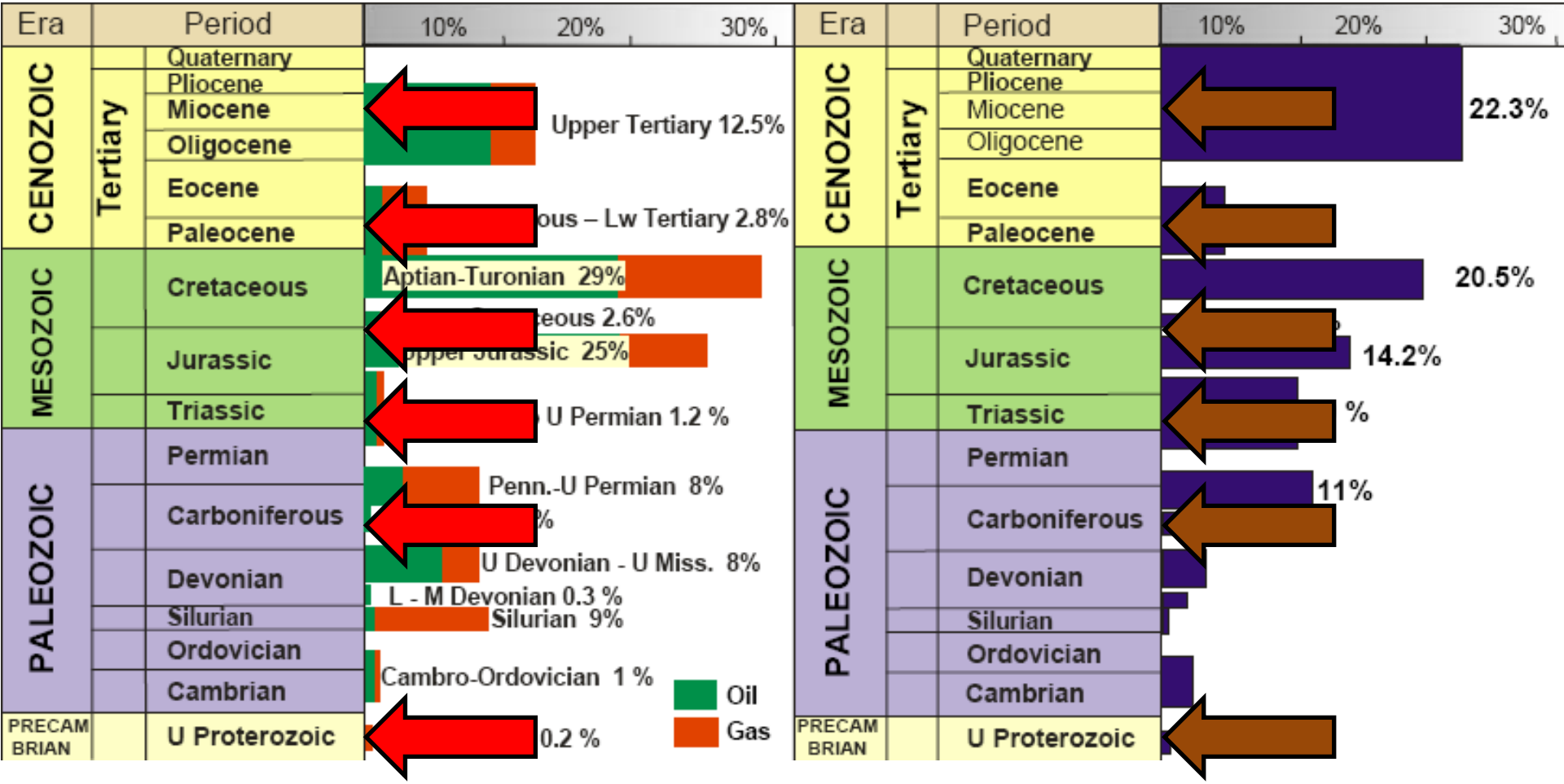


After: Magoon and Dow 1994 and AAPG

Time of Expulsion and Migration (Trap must already exist)

Data From: N.K. Verma et al., 2012; DeCelles et al., 1998b; Hodges et al., 1998; Meigs et al., 1995

Hydrocarbon Source and Reservoir Rocks through Geological Time



In Himalaya

Kendall et al., AAPG Search and Discovery Article #40472 (2009)
Originally from Ulmashek and Klemm, 1990

Summary and Conclusions

- Presence of the essential petroleum system elements at multiple stratigraphic levels through Neoproterozoic to Neogene
- Subathu Gp., Type III Kerogen, productive dry gas window, excellent source quality (Thickness: 80-100m, TOC: 4-5%, Ro: c. 1.41)
- Thrust tectonics cardinal to the maturity of shales, expulsion & retention of hydrocarbons
- Thick shales in inner belt with structures (triangle zones, pop-ups and duplex) > 3 Ma; prospective drilling targets
- Himalaya merits further hydrocarbon exploration albeit against some, environmental, technical, Socio-economic & political challenges

Thank you!