Characterization of Permian Mangrullo Formation (Uruguay) Oil Shale as a Source Rock and its Correlation with Iratí (Brazil) and Whitehill (South Africa) Formations*

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Abstract

During the Early Permian (Artinskian), a large inland sea developed across southern Africa and southern South America. These restricted conditions allowed the accumulation of organic matter and the deposition of oil shales. Mangrullo Formation, as defined in Uruguay, is a lithostratigraphic unit of Parana Basin constituted by oil shales, mudstones and carbonates developed in this depositional setting. The formation crops out in northeast Uruguay, reaching up to 35 meters in thickness. Regionally, the unit can be correlated with Irati Formation in southern Brazil and Whitehill Formation in South Africa and southern Namibia. In Brazil, subject to certain local conditions, the Irati shales have matured and generated. Heavy oil occurrences can be observed in the Permian sandstones of Pirambóia Formation, stratigraphically above Irati. However, the available outcrop and well data shows that Irati and Mangrullo shales are generally immature, mostly reaching the oil window through local heating by Early Cretaceous dykes and sills. This resource has been developed in southern Brazil since the 70s, involving its mining and the production of oil and gas through pyrolysis, on an industrial scale. An assessment made in the 80s at the Uruguayan side, estimated that 277 million barrels of oil can be obtained by pyrolysis of Mangrullo shales within a few areas studied. Despite the large research regarding pyrolysis of Irati and Mangrullo, there is not such knowledge of other potential uses for these resources, in particular, the production of energy through combustion processes. There is also an opportunity to properly characterize

Mangrullo oil shale to assess its source rock potential. The objective and contribution of this work is to characterize their source rock properties, by analysing core samples of a stratigraphic well located northeast of Uruguay and compare the results with Irati and Whitehill shales. Overall, the results indicate that Mangrullo can be termed as excellent quality oil and gas prone source rock, with high TOC% values and mostly type II kerogen. In the location of the well, the shales are just entering the oil window at a present-day depth of 20 metres, having generated a small amount of free hydrocarbons. It is expected that in the central and northwest region of the Parana Basin in Uruguay, where they are preserved at greater depth as recent well data suggests, these oil shales may reach enough maturity to generate significant volumes of oil.

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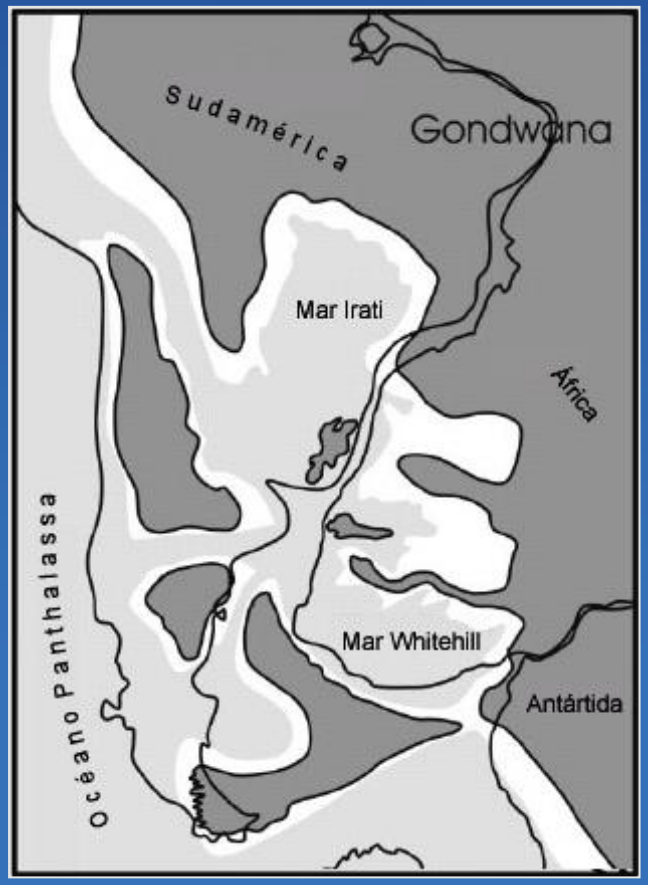
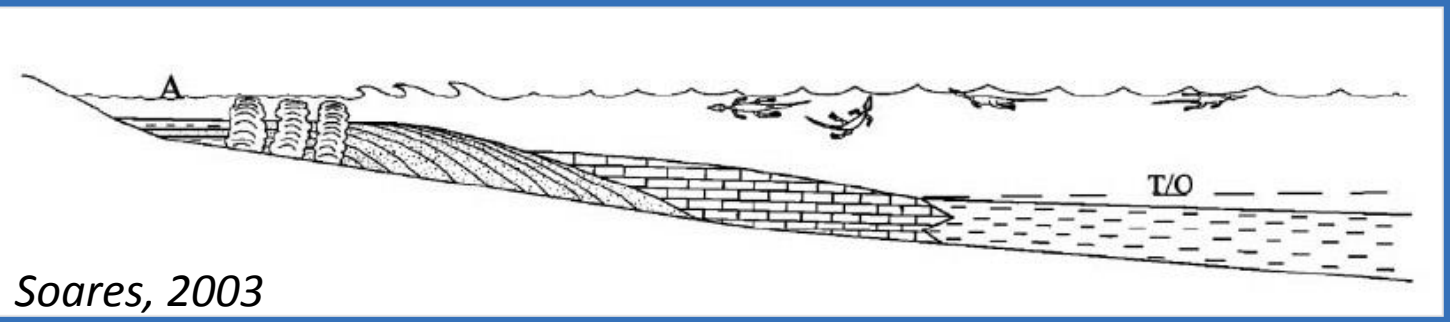
Objectives

- Characterize the Mangrullo shale of Uruguay as a source rock
- Analyse its oil shale potential and other potential uses such as co- combustion
- Compare the results with the analogous Iratí and Whitehill shales.

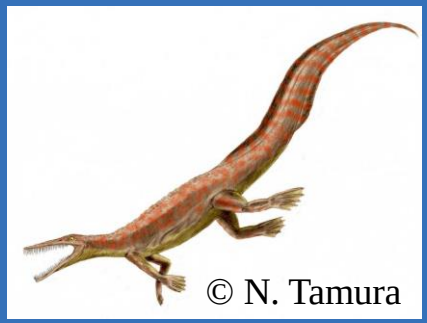
Introduction

- Early Permian, Gondwana
- Large inland sea (southern Africa and South America).
- Restricted conditions: accumulation and preservation of organic matter.
- Oil shales in the Main Karoo and Parana basins



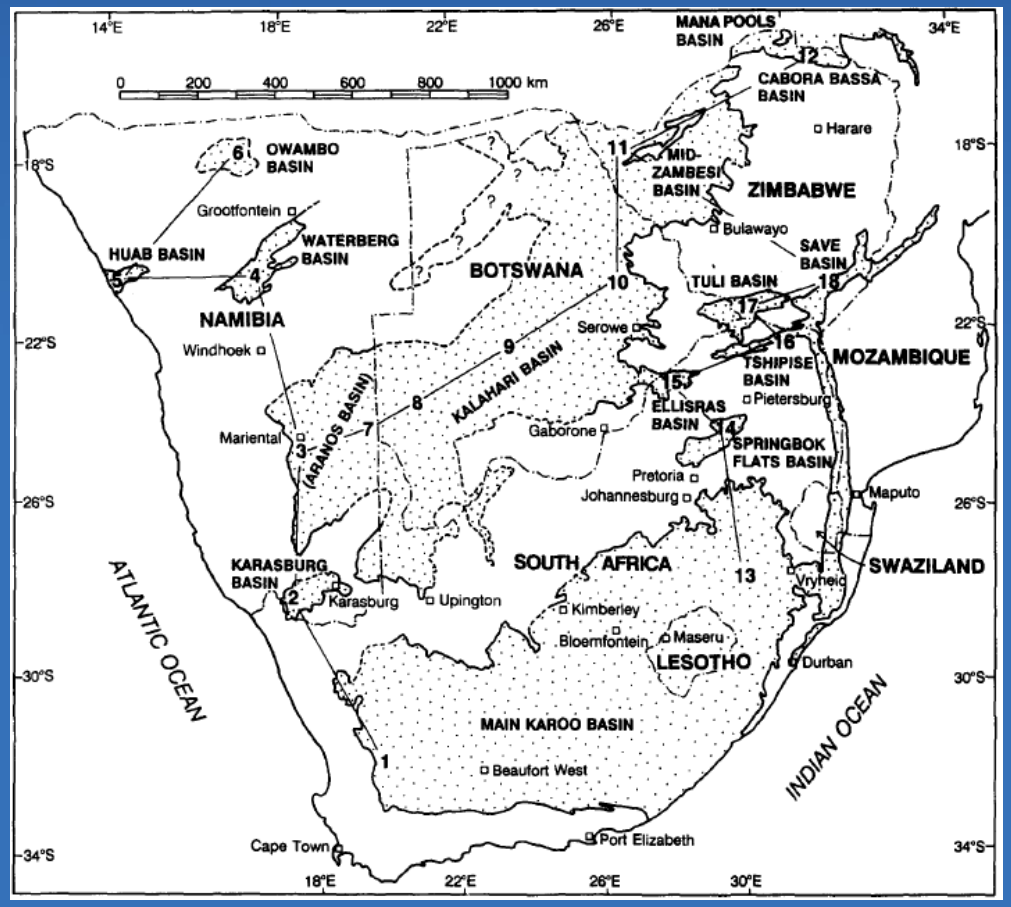


Soares, 2003



Introduction: Karoo

- Late Carboniferous to Early Jurassic.
- Outcrops in Namibia, Swaziland, Zambia, Zimbabwe and Malawi.
- Main depocenter is located in South Africa (Main Karoo Basin).



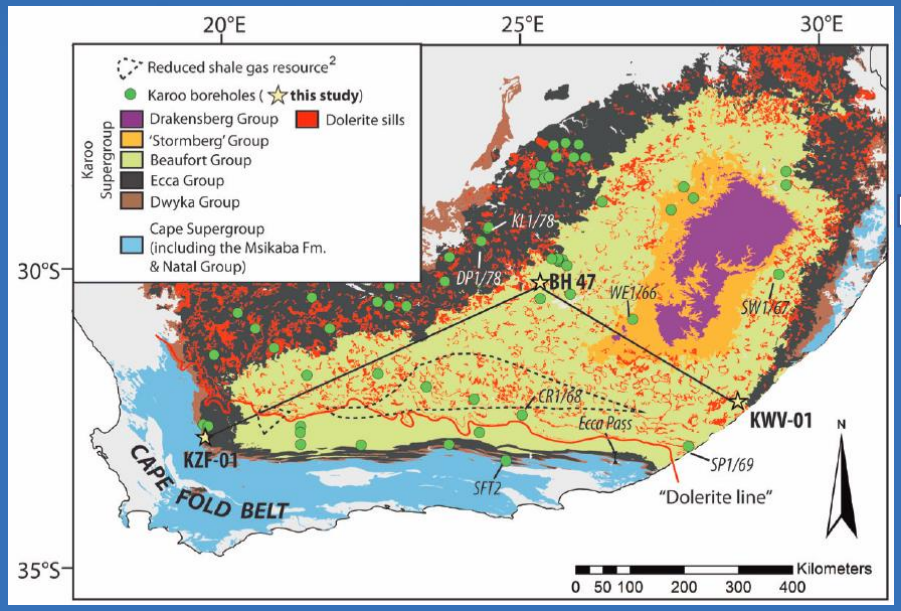
Johnson et al, 1996

Whitehill

- Thickness: 30 – 60 m organic-rich shales
- Over mature: dykes & sills(KLIP), thermal tectonism (CFB).
- Shale gas potential.

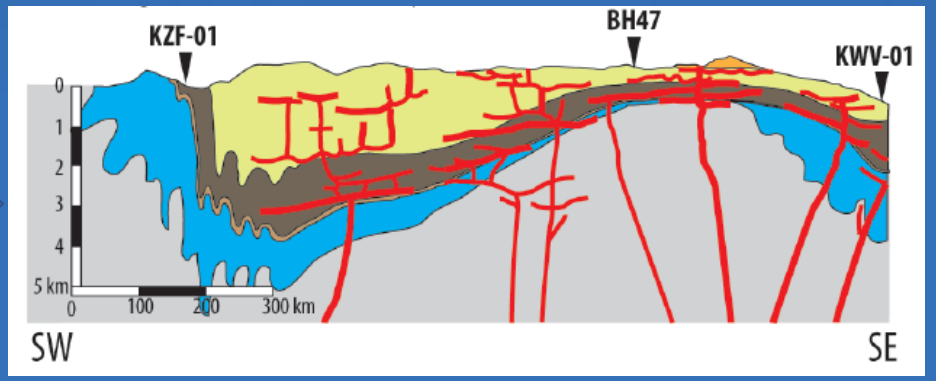
From: de Kock et al (2017)

Main Karoo Basin

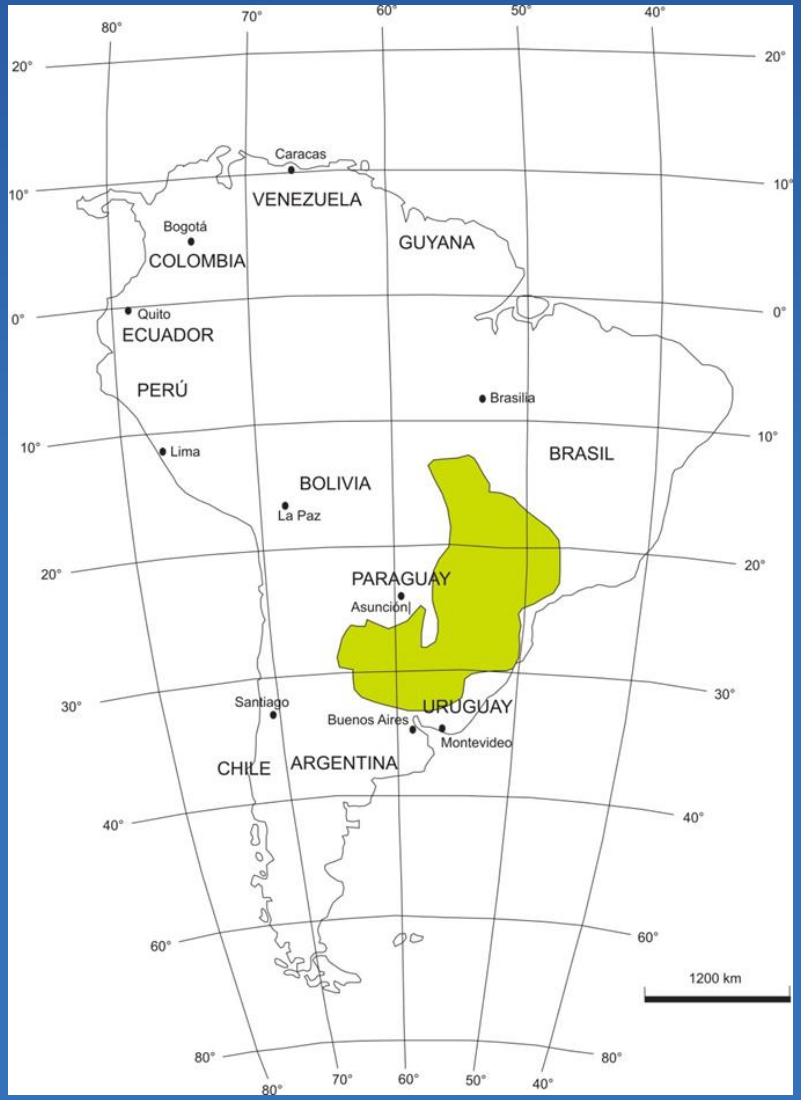


de Kock et al 2017

Cross section



Introduction: Parana



- Intracratonic basin (1,400,000 km²).
- NE Argentina, S Brazil, SE Paraguay and N Uruguay.
- Vulcano- sedimentary infill, Neo-Ordovician to Neo-Cretaceous.
- Maximum thickness ~ 7000m
- Early Permian oil shales (equivalent to Whitehill): Iratí Fm. in Brazil Mangrullo Fm. in Uruguay.

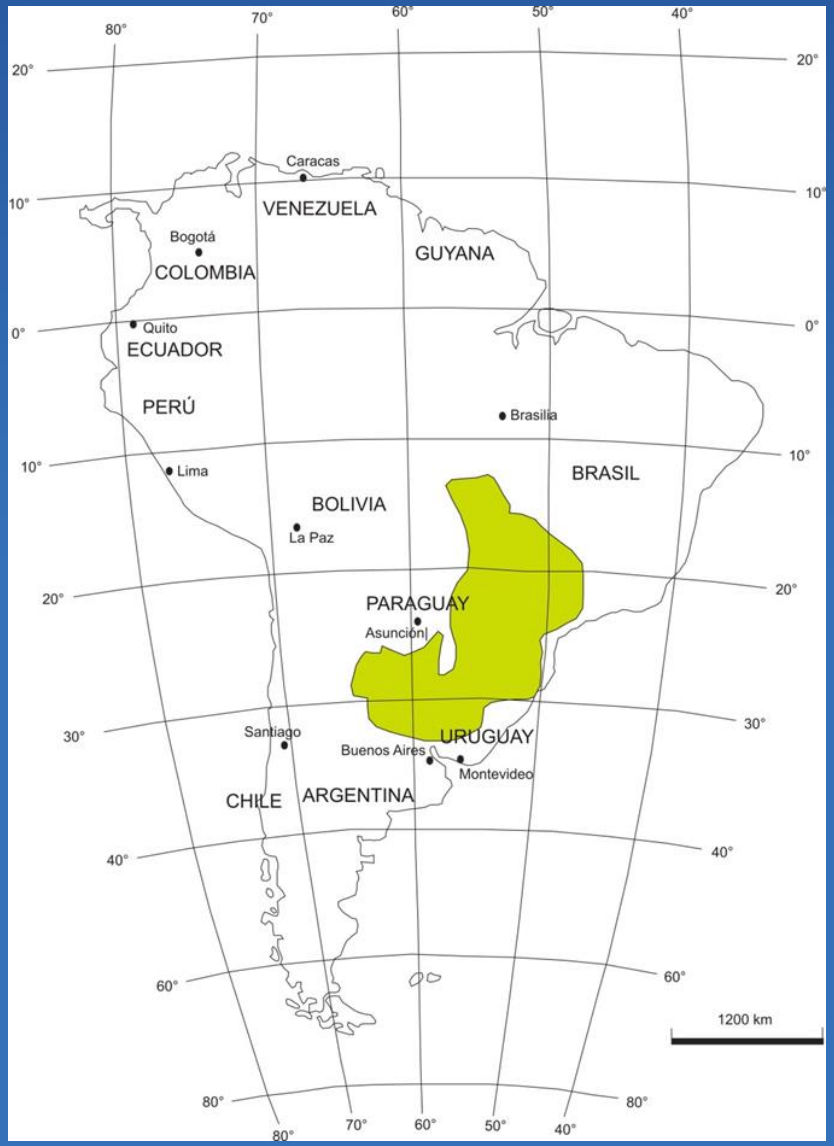
Iratí

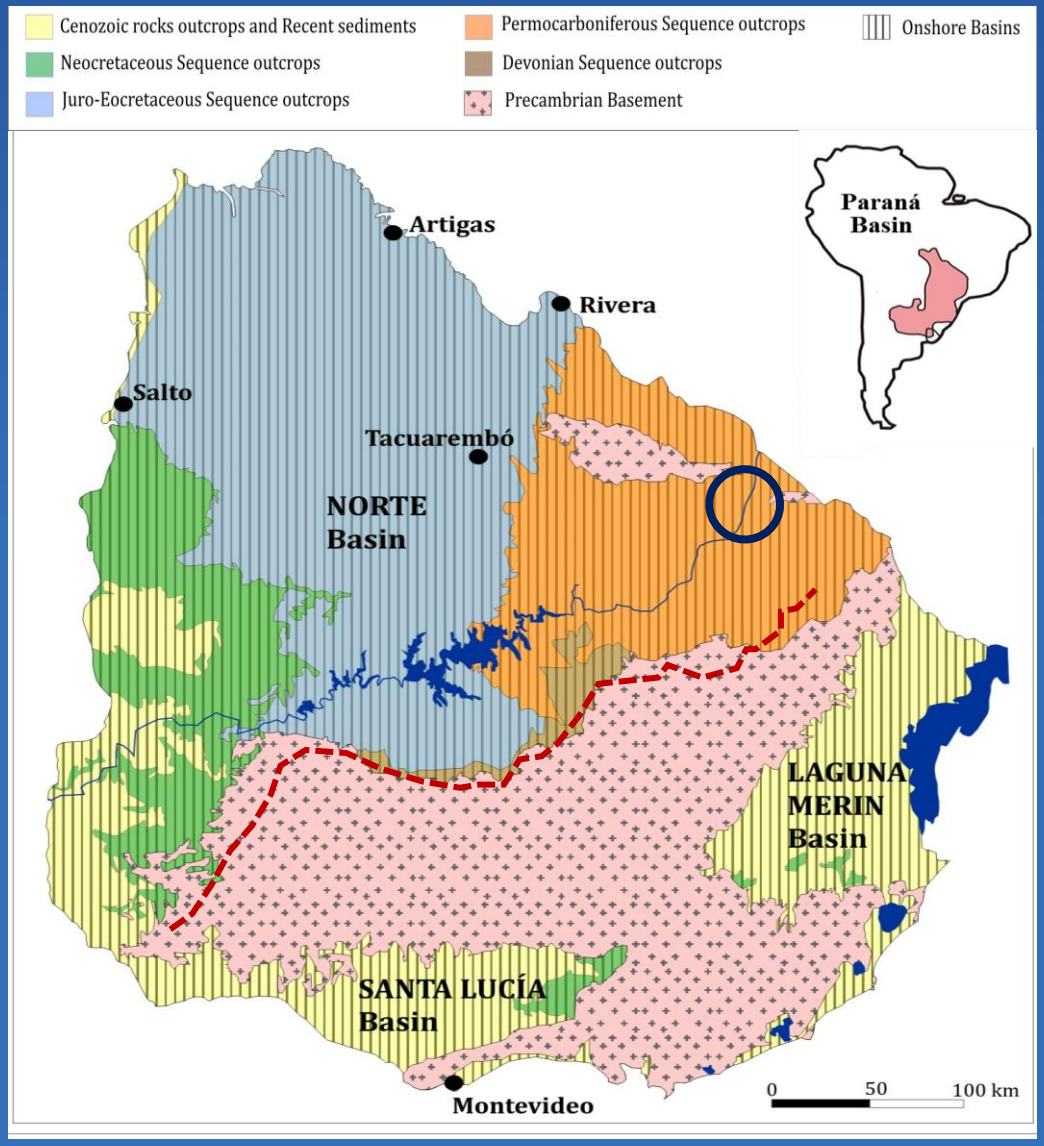
- Average thickness: 40 m.
- Mostly immature, except from basin depocenter or local thermal effects associated w/ sills & dykes.
- Industrial pyrolysis since 90s.

From: Da Silva & Cornford (1985), Euzebio et al (2016)

Oil shale processing plant, São Mateus - Brazil

Introduction: Norte basin





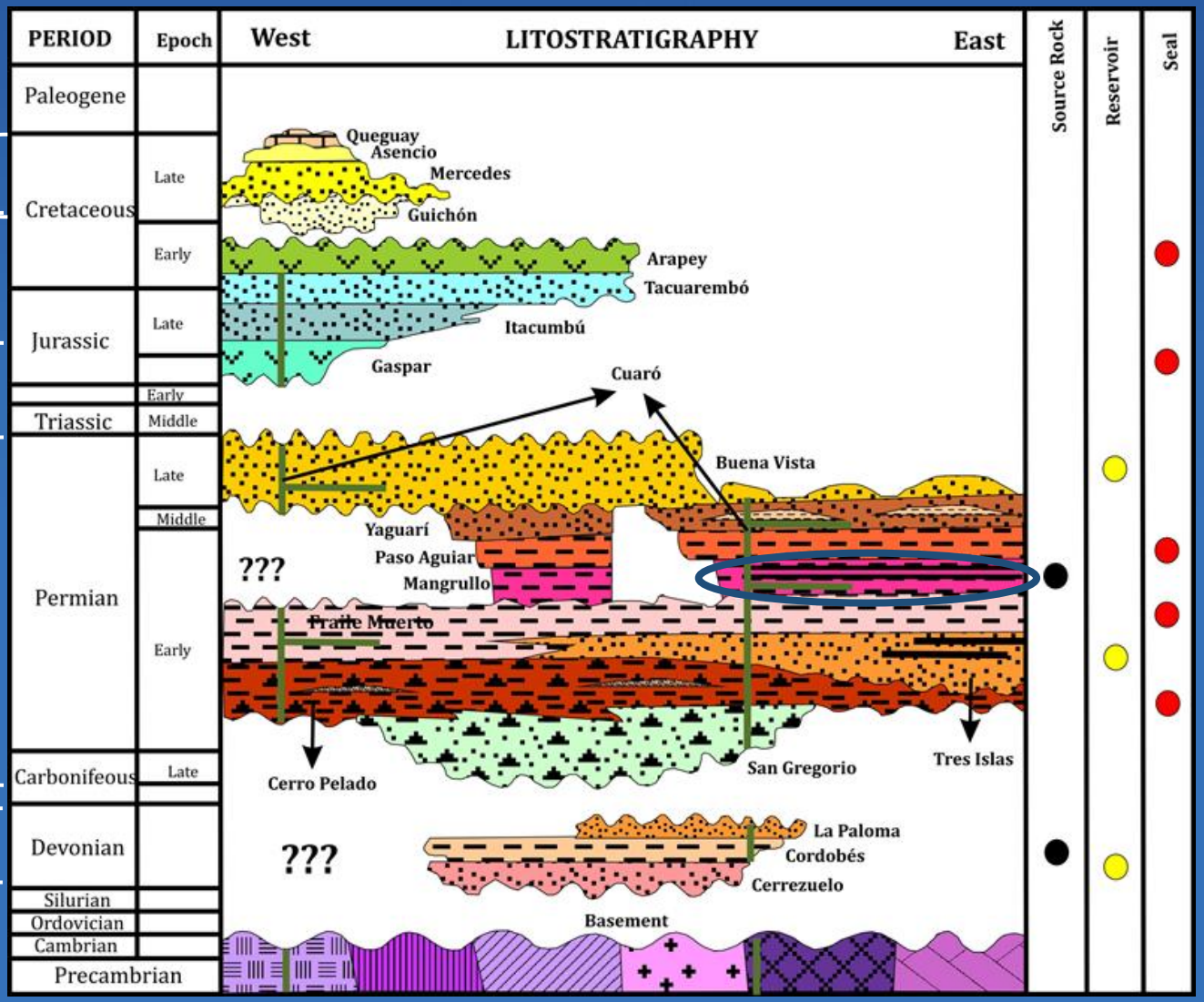
Introduction: Norte basin

L. Cretaceous 4

Jurassic - E. Cretaceous 3

Permo - Carboniferous 2

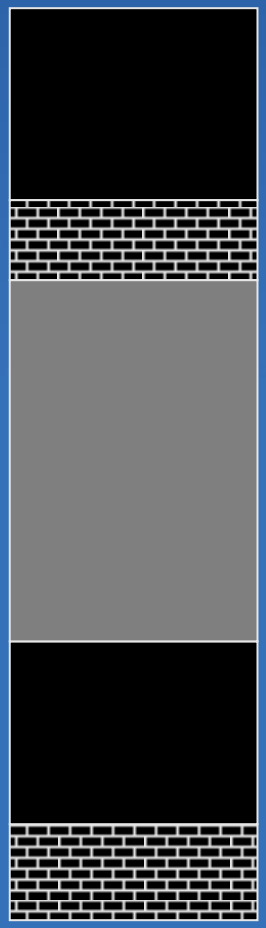
Devonian 1



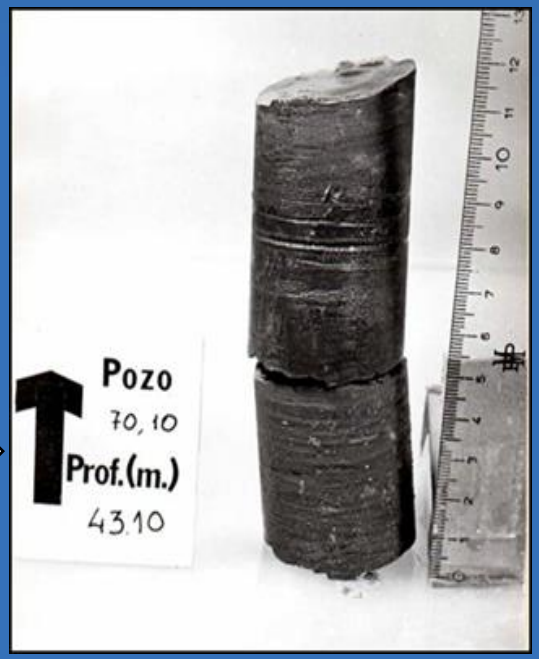
Modified from: de Santa Ana, 2004

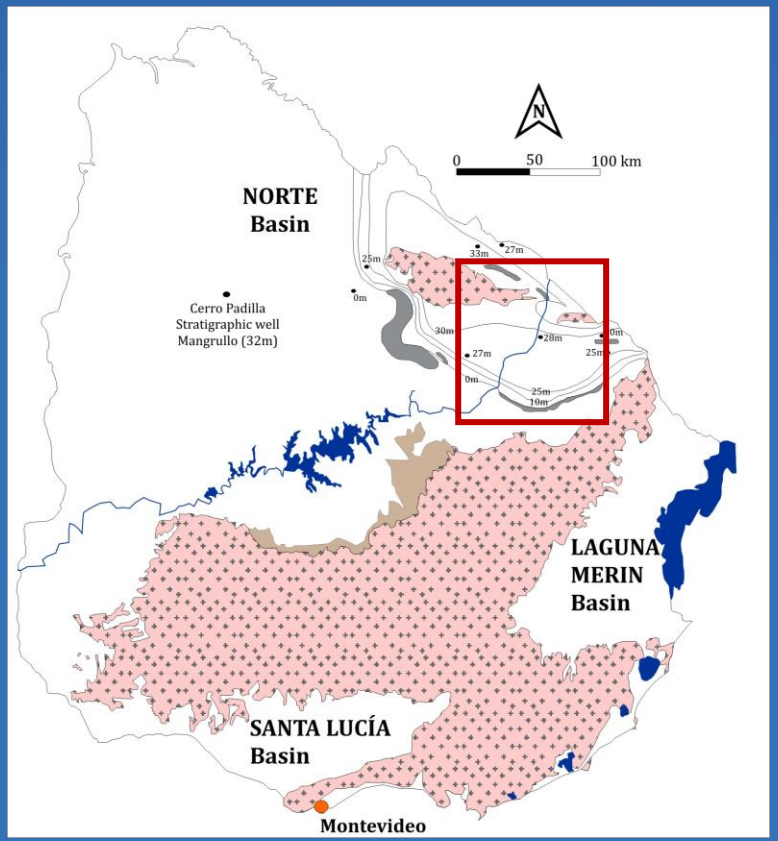
Mangrullo

- Outcrops NE Uruguay: organic-rich shales, mudstones and carbonates, up to 35 m.

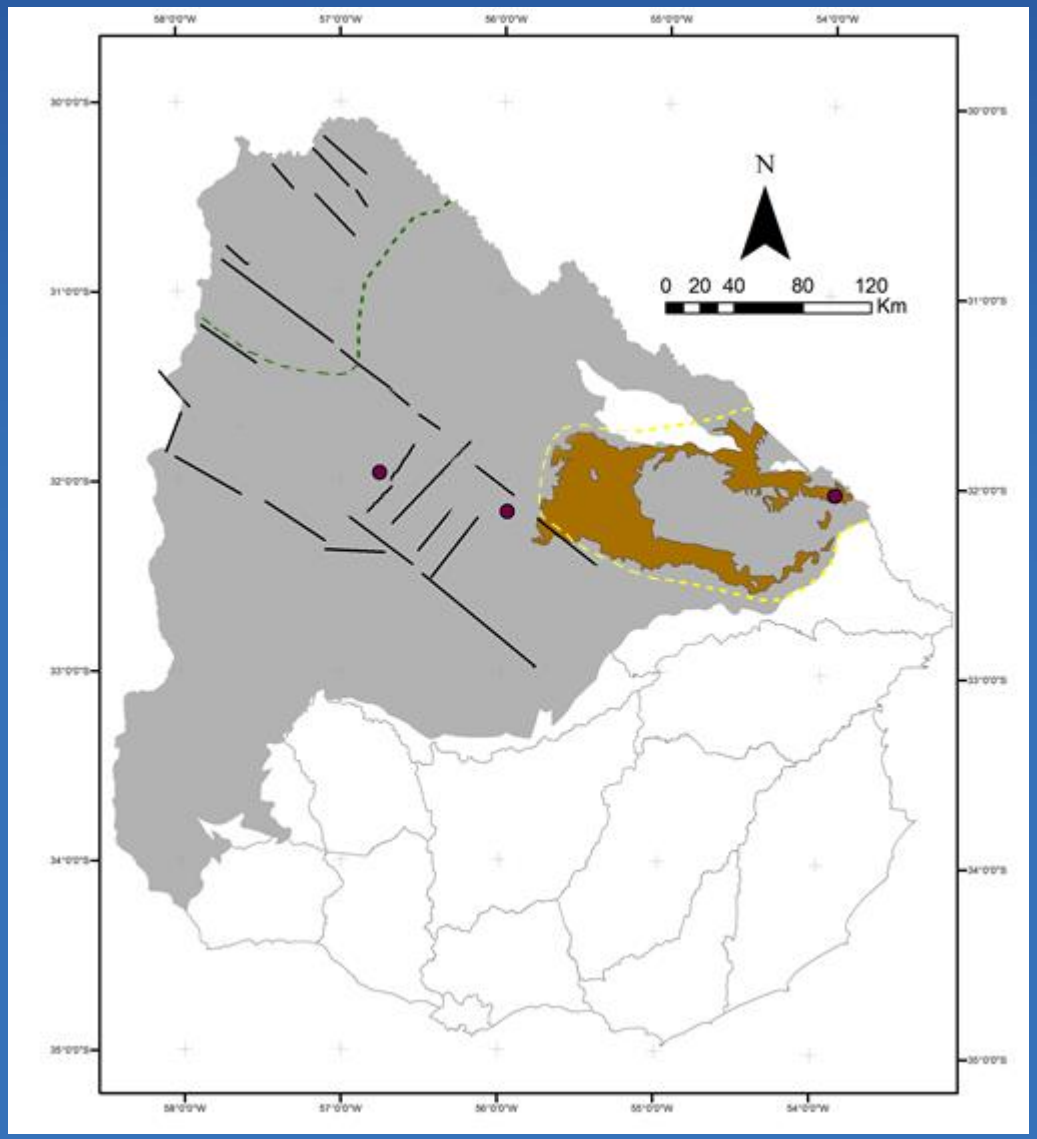


Mangrullo cores from the second bed





Methodology

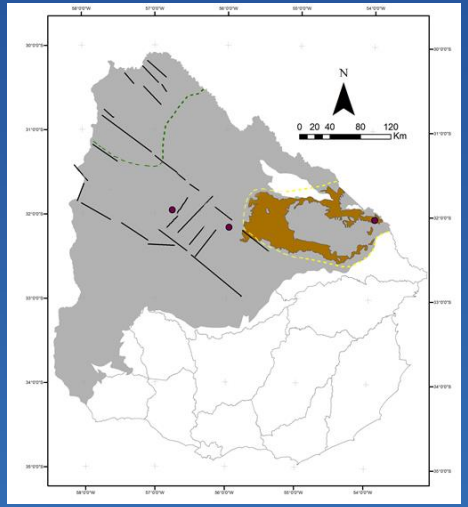


Organic geochemistry (TOC & Rock Eval) & organic petrology, on well samples:

- **X1** well (cores), near outcropping area, Mangrullo @ 20 m
- **X3** exploration well (cuttings), Mangrullo @ 736 m

Results

- Good to excellent source rock quality.
- Oil & gas prone.
- Immature, entering oil window at X1 location.



Parameters	X1 well (1)	X3 well (2)
Present day Depth (m)	20	736 – 751
TOC (%)	8.93	1.87 – 2.96
S1 (mg/g)	2.02	0.10
S2 (mg/g)	46.92	2.8 – 9.2
Tmax (ºC)	399	435 – 436
HI (mgHC/gTOC)	525	148 – 311
OI (mgCO2/gTOC)	20	72 – 25
VRo%	0.61	0.36 – 0.39

(1) Torres et al (2018); (2) Unpublished (ANCAP, 2018)

Results

Geochemical correlation:

	Mangrullo (1)	Iratí (2)	Whitehill (3)
TOC (%)	2 – 9	0.4 – 12	3 – 14
Ro%	0.36 – 0.61	0.34 – 0.40	2 – 4
	Oil shale & combustion potential		Shale Gas potential

(1) From this study.
(2) From Euzébio et al (2016), Da Silva & Cornford (1985).
(3) From Adeniyi et al (2018).

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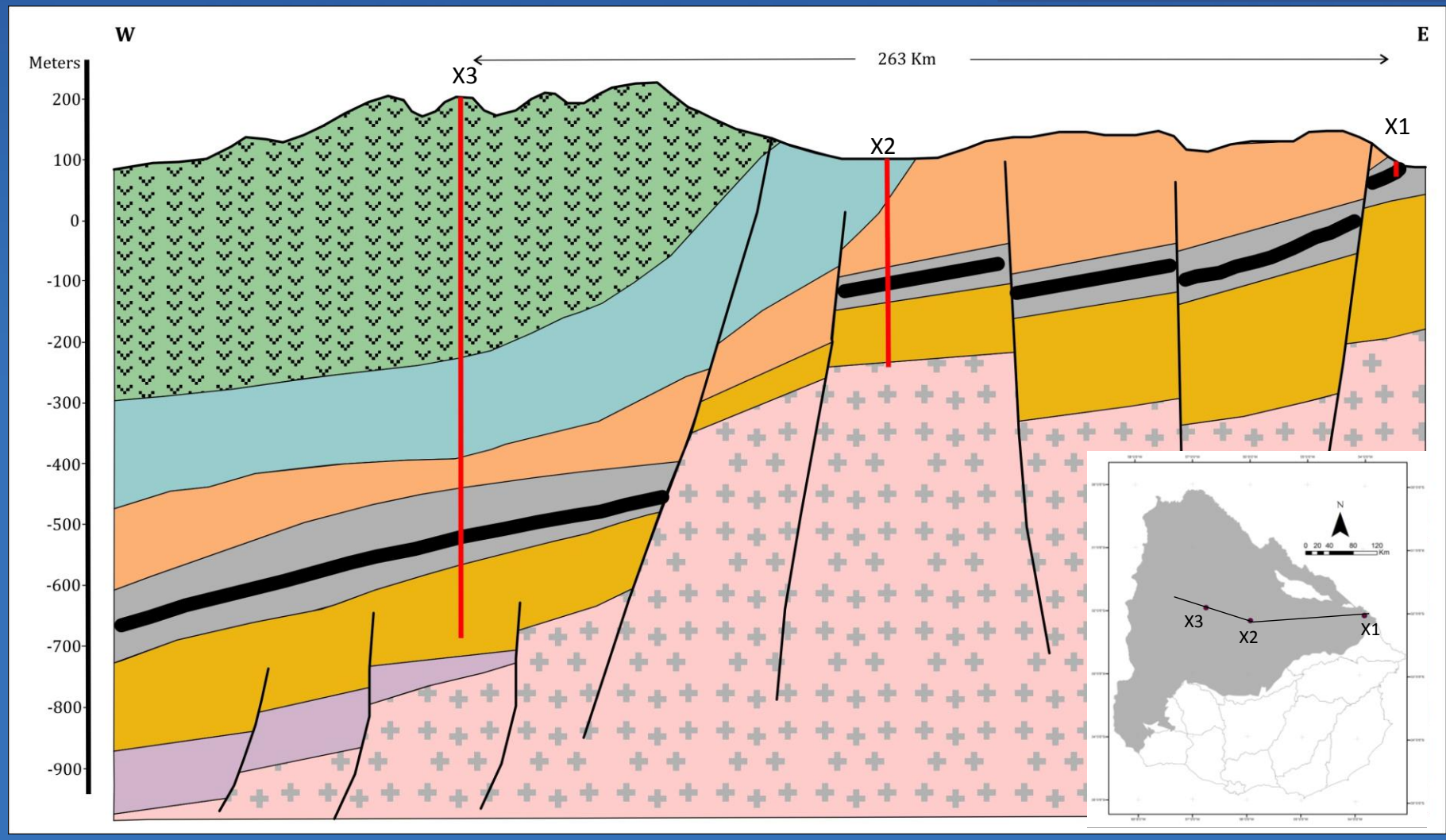
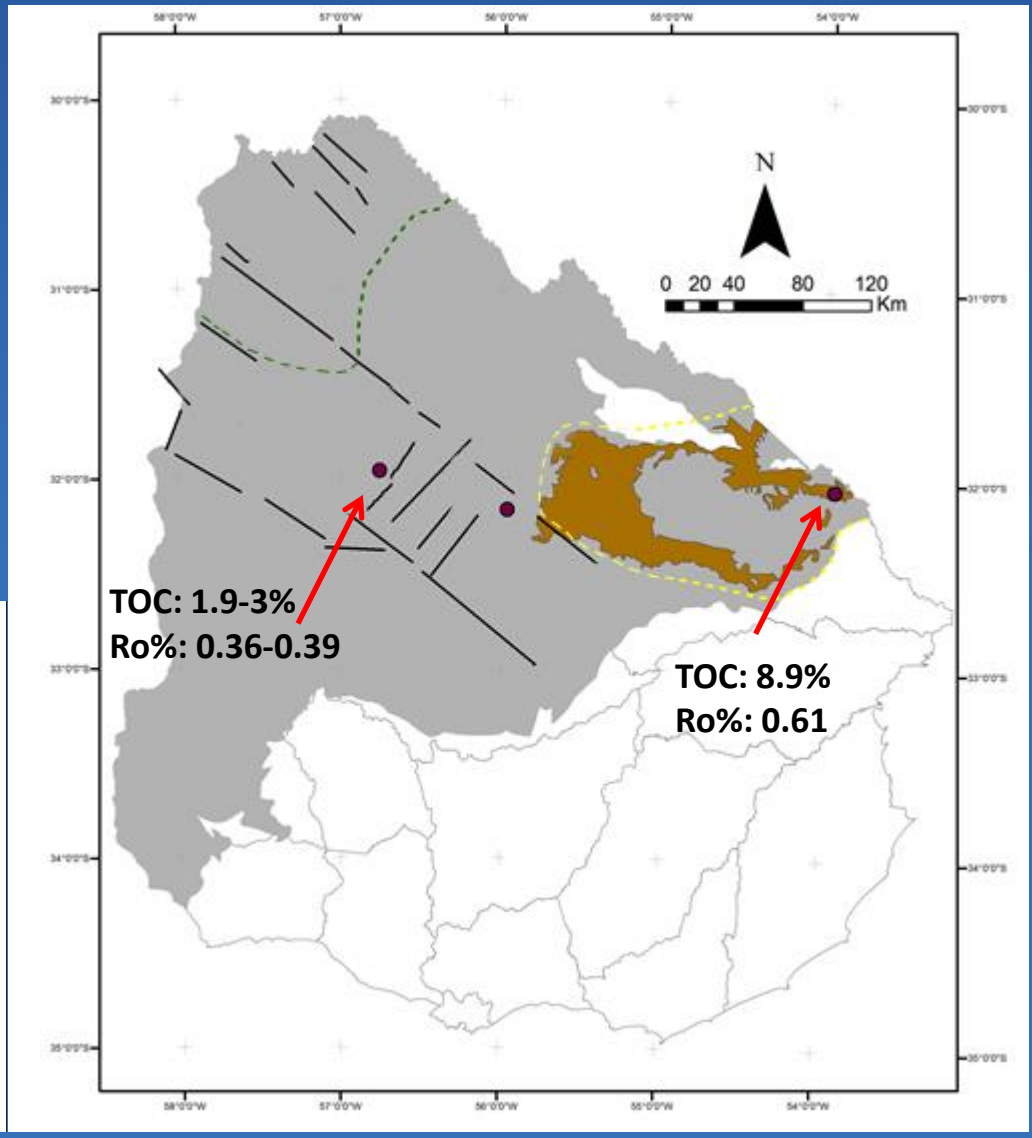
Mangrullo: E – W cross section



Mangrullo: maturity



References

- Norte Basin
- Mangrullo outcrops
- Main structures
- Mangrullo: Oil shale potential (inmature)
- Mangrullo: Source rock potential (oil window)
- Analyzed wells

Mangrullo: combustion

- Relatively low heating values, organic matter heavy diluted in the inorganic matrix.
- Potential for co-combustion with solid fuels (biomass waste).

Chemical properties of the Uruguayan OS compared with other OS of the world.

Region	Ultimate analysis (wt%)					Proximate analysis (wt%)			Calorific value (MJ kg^{-1})	
	C	H	O[γ]	N	S	VM	FC[φ]	Ash	HHV	LHV
Mangrullo[a] (Uruguay)	9.3	2.3	11.6	0.2	4.0	24.0	3.4	72.6	3.2	2.8
Huadian[b] (China)	29.2	4.3	4.1	0.6	4.9	39.3	3.8	56.9	*	13.1
Irati[c] (Brazil)	16.5	1.8	0.3	0.5	4.0	*	*	76.9	*	*
Nongan[b] (China)	9.7	1.0	–	0.3	5.7	9.7	1.6	89.3	*	2.9
Estonia[d, e, f]	27.4 – 30.4	2.7 – 3.0	23.6 – 27.7	0.07 – 0.1	1.6	47.5 – 49.6	1.1 – 1.3	49.3 – 50.7	8.6 – 11.9	8.5 – 11.0
Kentucky[g] (USA)	10.3	1.3	1.7	0.4	2.7	*	*	83.6	*	*

VM: volatile matter, FC: Fixed carbon. All values are expressed in dry basis.

Torres et al 2018

Conclusions

- Same lithological unit deposited in Gondwana, but different tectonic and thermal evolution.
- Whitehill: over matured; Mangrullo & Iratí: immature (at shallow depths, if no effect from sills & dykes).
- Mangrullo in Uruguay: source rock potential (depocentres) and oil shale potential for pyrolysis & co-combustion (outcrops).
- Further exploration and geochemical analysis are required to better understand the evolution of the basin and its hydrocarbon potential.

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