

# **A Royal Flush in the Great Campos (Brazil's Santos-Campos) Basin\***

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Search and Discovery Article #10994 (2017)\*\*

Posted October 2, 2017

\*Adapted from oral presentation given at 2017 AAPG Annual Convention & Exhibition, Houston, Texas, April 2-5, 2017

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## **Abstract**

Eighteen months prior to the Tupi discovery, a multi-disciplinary study predicted Santos Basin pre-salt sourcing working from non-exclusive data: key piston cores, a satellite SAR interpretation, 2D basin modeling, source rock screening, and a few crude oils. With detailed geologic reasoning a nearly busted flush in the Santos Basin became a winning hand.

One face card was a piston core macro-seepage, extensively degraded, that still correlated to lacustrine oils from the Cabo Frio area, proving an active pre-salt source. Concurrently, a 2D compositional model predicted oil generation from a pre-salt Guaritiba lacustrine source in the basin center. With an impervious salt layer (as seen on a regional seismic composite profile) providing a barrier to vertical migration, the model predicted long-distance lateral migration to the basin margins before oil escaped vertically. A SAR study confidently identified seepage within the basin and, at lower confidence, dispersed seepage along the margins. Localized maturity of the post-salt Itajai-Acu source meant no expulsion paths existed from mature Itajai-Acu to the distal basin margin. That left lateral migration below the salt to reach the margins, hence filling any pre-salt traps before excess hydrocarbons escaped.

From proving a working pre-salt source to inferring source interval depositional environments took more time and fluid samples. Current work is based on a much-expanded set of ~500 fluid samples from which four main oil families can be distinguished across the Campos and Santos sub-basins. A multivariate statistical comparison first separated a group of pre-salt oils derived

from source rocks composed of a mixed (lacustrine algal + marine algal) kerogen assemblage deposited in sag basinal settings. Strong chemical similarities suggested a genetic relationship among oils from wells dotting the ANP “pre-salt polygon” area. This family of oils often overlaps expulsion area of another family from an older Syn Rift II lacustrine brackish setting (Lagoa Feia). Two further types derive from mature source rocks deposited in either earlier Syn-Rift I lacustrine freshwater environments or younger, post-salt Late Cretaceous marine settings. We discuss resulting oil mixing plus geochemical, tectono-structural and inferred environment of deposition settings of these families to illuminate the charge story of the Santos and Campos super-giant fields, discoveries and YTF (yet-to-find)!

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# A Royal Flush in the Great Campos (Brazil's Santos-Campos) Basin

**Type Study in Detecting and Deducing a  
Super-charged Pre-salt Petroleum System  
from Scant, Disparate Data**

*by Craig F. Schiefelbein (GSI)  
and  
William Dickson (DIGs)*



## ***Brazil SE Margin: Area of Work and Project Rationale***



Early success in the Campos Basin found a series of giant oil fields reservoired in post-salt turbidites and sourced primarily from the now-classic pre-salt Lagoa Feia intervals. Early exploration in the adjacent, co-eval Santos Basin was mostly unsuccessful despite indications that it contained similar sources. Santos was set aside as a gas-prone afterthought.

The authors, through a four-year multi-disciplinary collaboration, developed a Santos hypothesis of an effective basin-wide pre-salt source. A poster at AAPG Calgary in 2005 presented their ideas which are reviewed and updated in this talk.

## ***Talk Outline***

- Introduction
- Key Process Map
- Major Tectonic Elements
- Exploration History, Campos vs Santos
- Source Family Inferences from oils, SGE, slicks
- Hydrocarbon Migration Story
- Then vs Now: Understandings of 2005 vs 2015

Presenter's notes: Oils from well tests and as eluted from cuttings and/or conventional cores. SGE = Surface Geochemical Exploration, in this case with seafloor darts (Piston Cores). Slicks are inferred from satellite imagery, usually SAR (Synthetic Aperture Radar).

# ***Key Process Map: Tools & Data***

## Geoscience CSI

- Use all the tools
- Cross-verify all the clues
- Rinse; repeat.

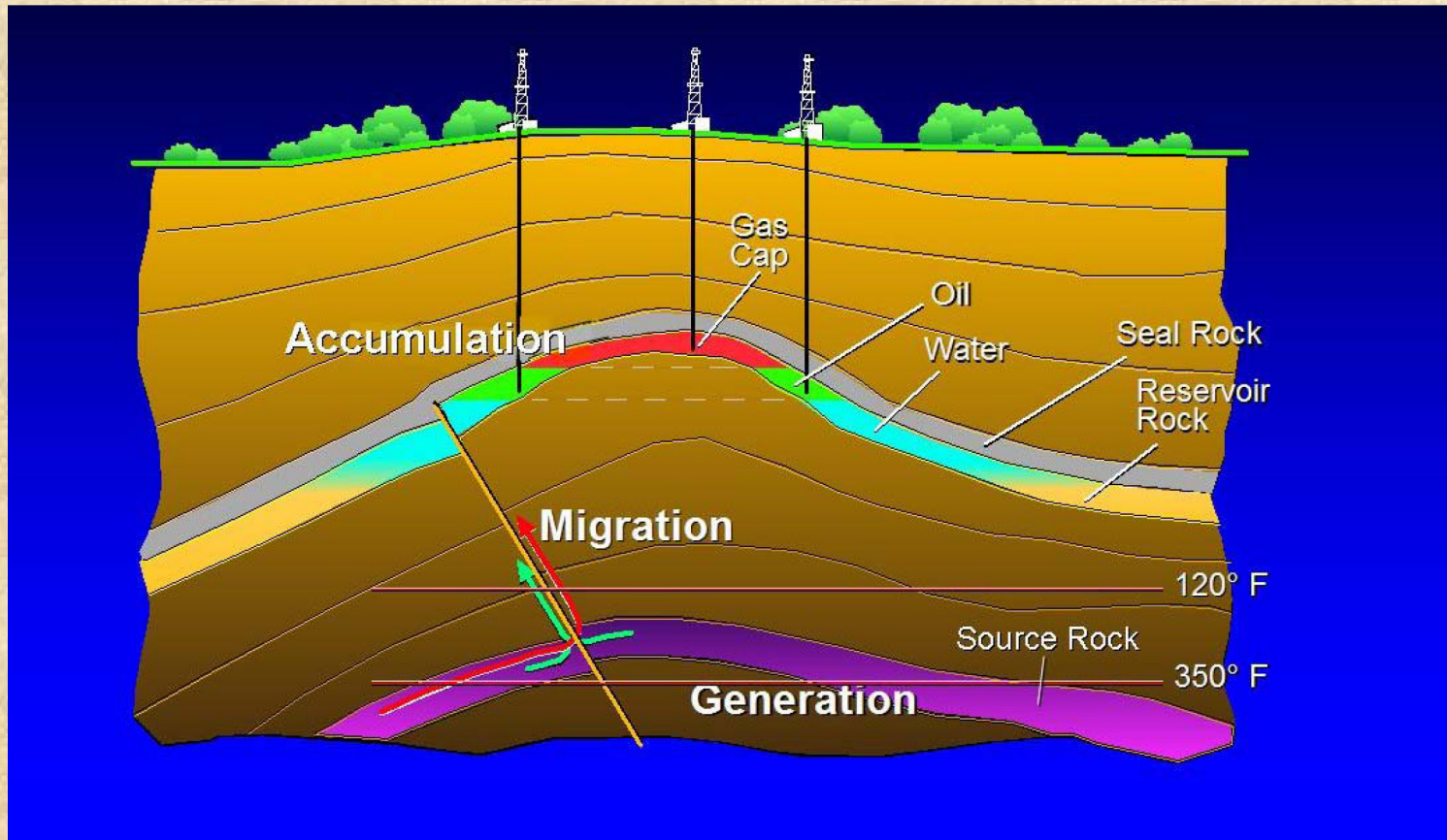
© & Photo Credit Jan Christ, 2004



## Data sources

- Non-exclusive or licensed & published
- Surface & sub-surface
- Sparse & detailed

# ***Geo-Crime Scene Investigation***

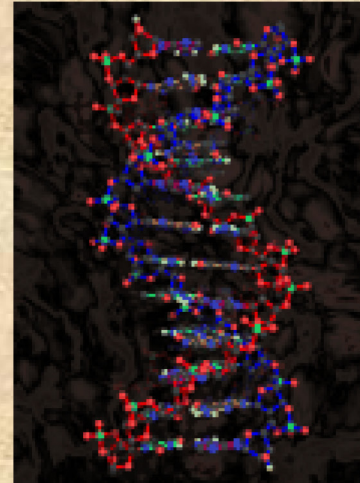


- Recreate crime scene in petroleum system context
- Crude oils are compositional derivatives of source rocks
- Use all tools & clues – avoid the box / silo
- *Caveat* false positives
  - fake / bad slicks, buggy geochem / correlation vs causation

## ***Genetic Classification of Oils***

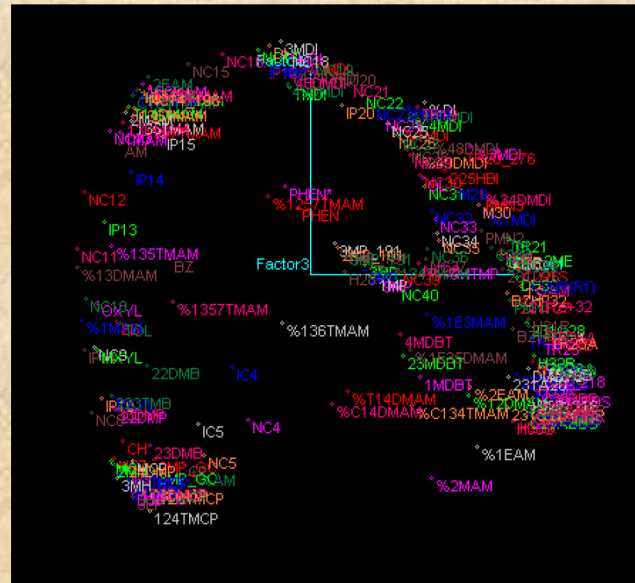
**Similar approach as in DNA paternity tests:**

## Parent $\leftrightarrow$ Sibling

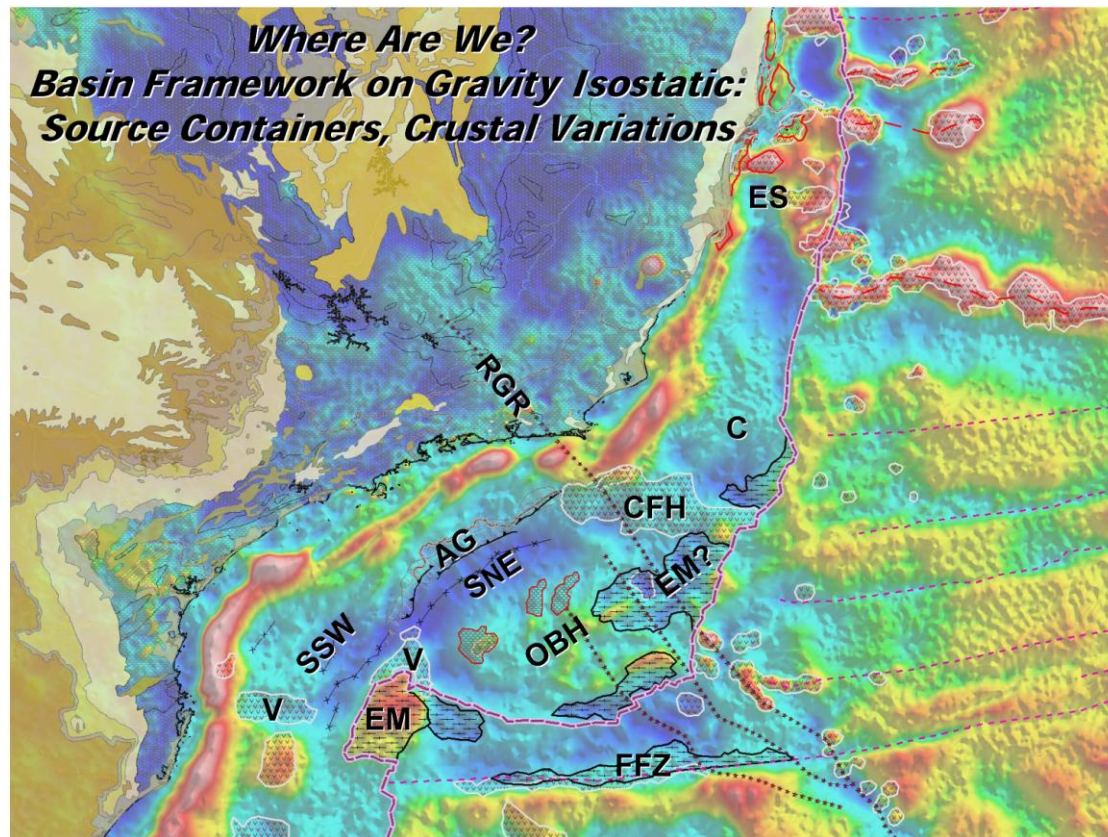


# DNA Double Helix

**Quantitative compositional data drives Oils  $\leftrightarrow$  Source Rocks linkage BUT source rocks, esp. mature, rarely available for study!**

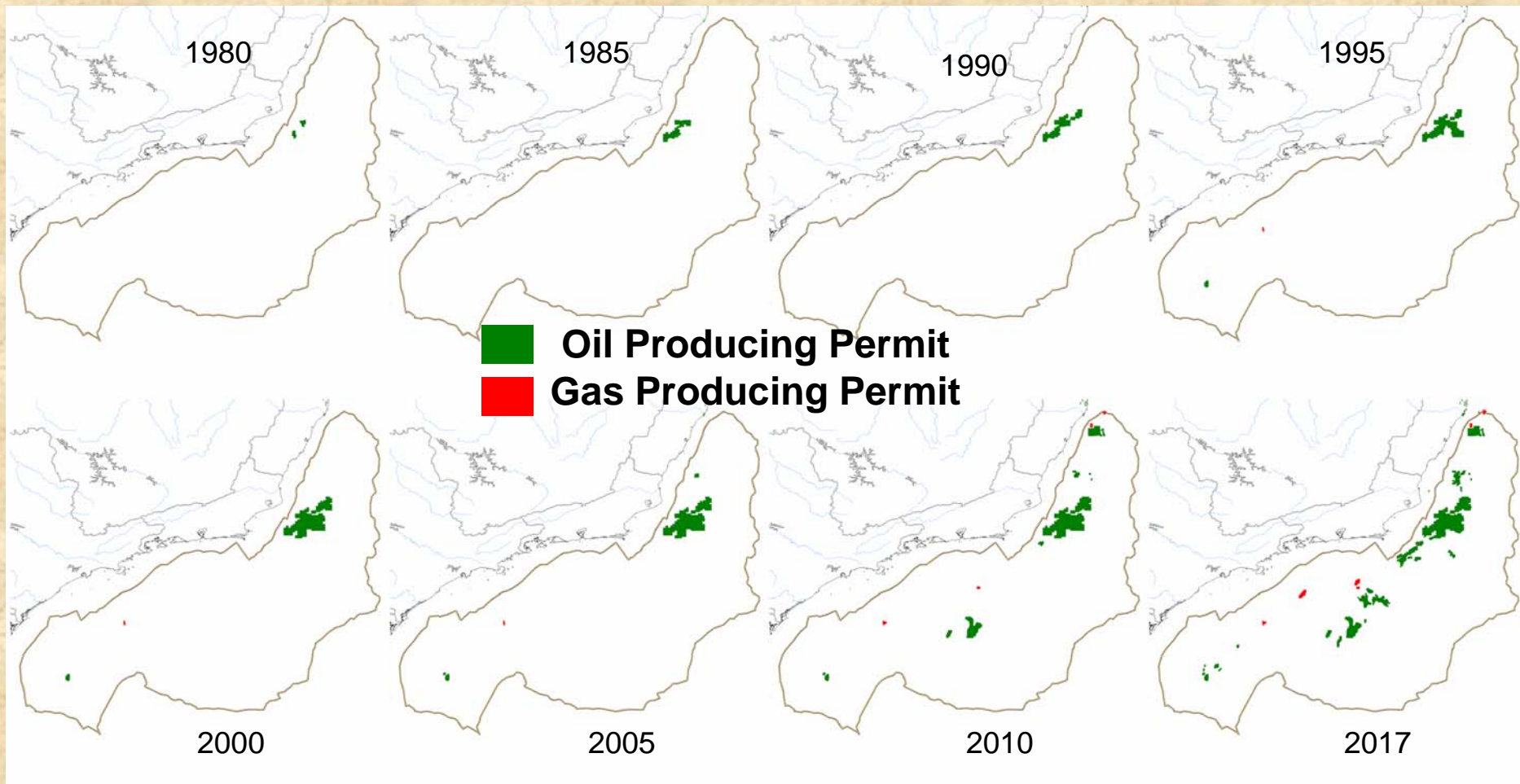


# Geochem Data Point Cloud



Presenter's notes: Crustal features interpretation on backdrop of Gravity Isostatic Residual Anomaly (GI) with onshore geology after USGS 1:5 mm map of South America. Key basin axes show as GI lows (blue); basin margins as GI highs (reds). Abbreviations: AG = Albian (stratigraphic), Gap (produced by gravity gliding); ES = Espírito Santo Basin; C = Campos Basin; CFH = Cabo Frio High (Eocene Thermal effect); EM = Exhumed Mantle (from the failed South Atlantic Propagator); FFZ = Florianópolis Ridge/Oceanic Fracture Zone; OBH = Outer (Santos) Basin High; RGR = Rio Grande Rise Hot Spot Track; S = Santos Basin (SNE = Santos Northeast; SSW = Santos Southwest) Northernmost effect of the South Atlantic Propagator effectively separates the Santos into SSW & SNE with markedly different results on the ensuing salt distribution and movement. By contrast, the Cabo Frio High is a post-rift (Eocene) thermal effect which did not influence the distribution of the pre-salt source intervals from Santos (Guaritiba) across Campos & Espírito Santo (Lagoa Feia).

# *Exploration History: Campos leads, Santos lags*



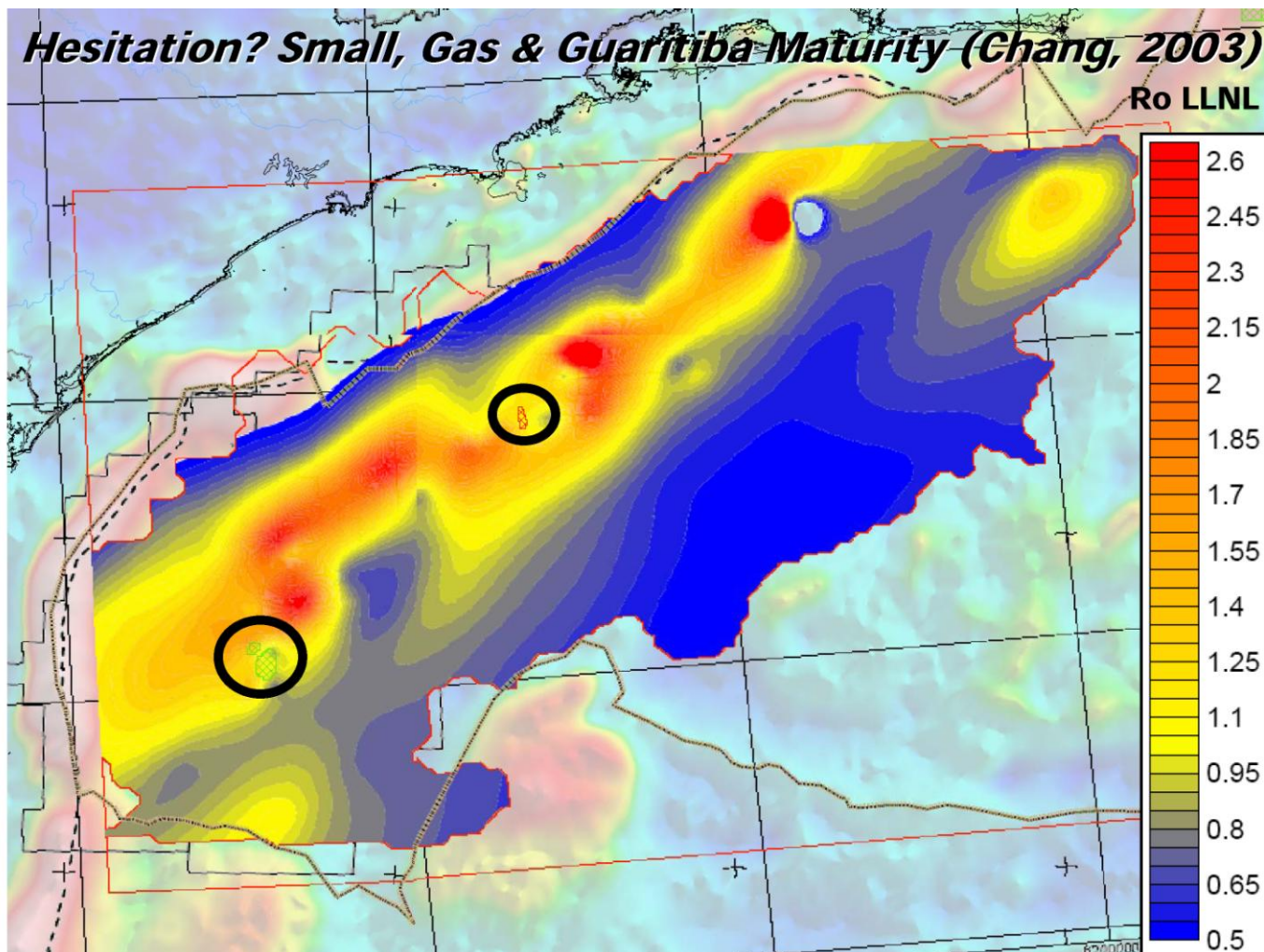
Santos the laggard basin (*from Feijo 2013\**):

1970–1987: 59 dry holes; one discovery (Merluza, 70 BCF, Pecten, 1984)

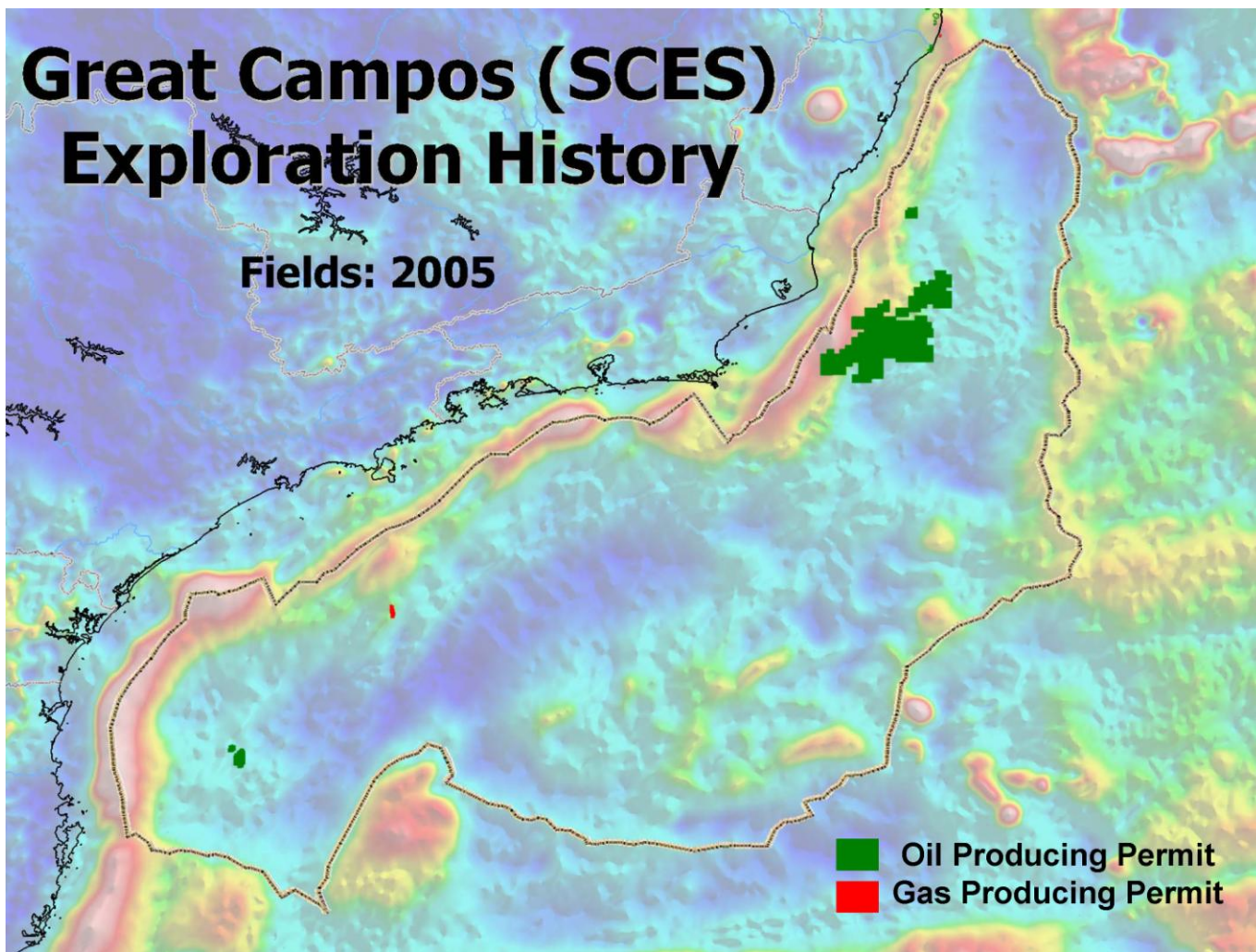
1988–1998: 45 wells, five small discoveries: Tubarão 30 MM bbl, 1988; Estrela do Mar, Coral, Caravela, Cavalo-Marinho TEC3

1999–2005: 81 wells, medium-sized discoveries: Tambuatã, 1999; Mexilhão, 2003; Lagosta, Pirapitanga, Tambaú, Uruguá, Carápia, Oliva, Atlanta

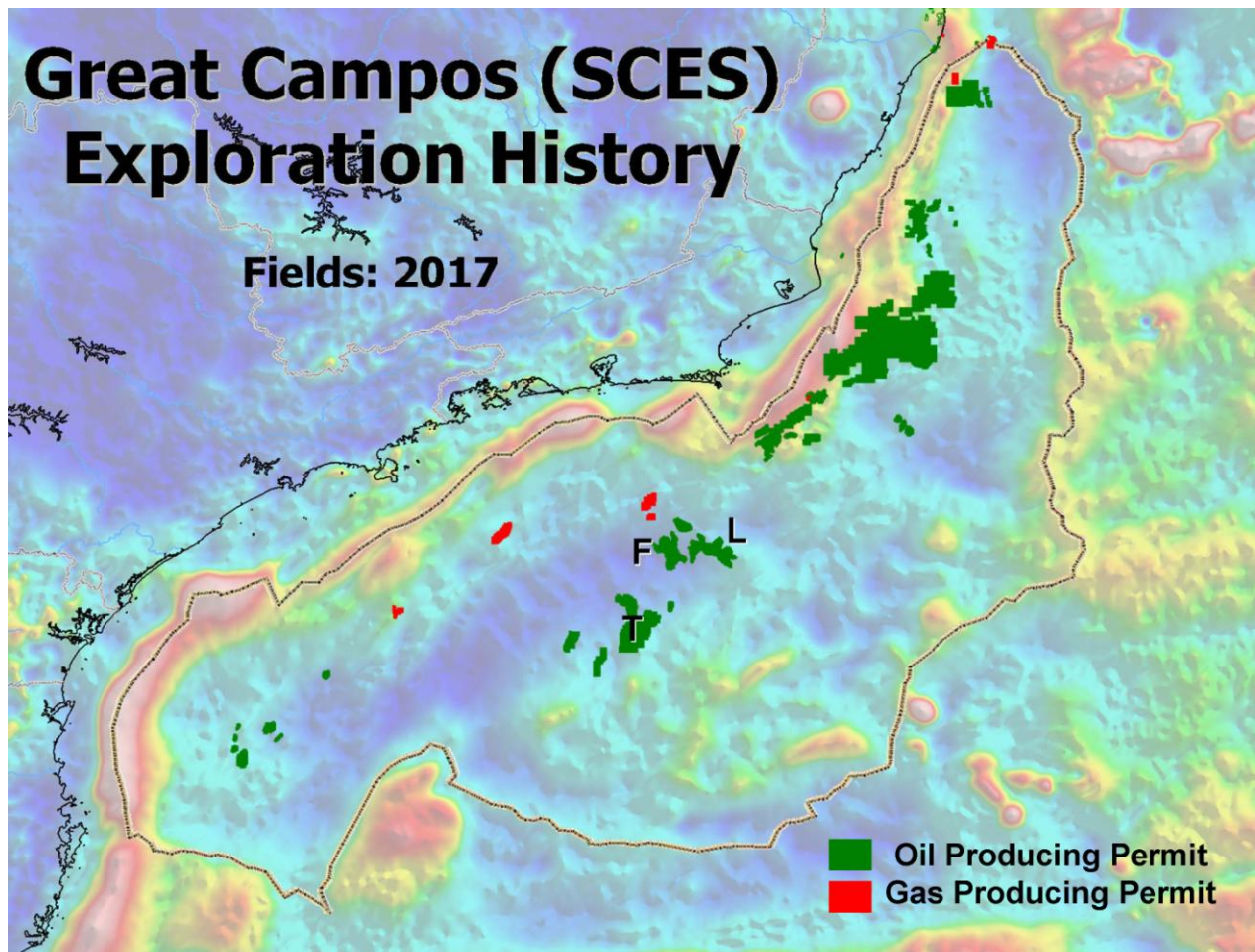
2006–2012: Pre-salt at last! with 166 wells yielding Giant & Super-giant discoveries



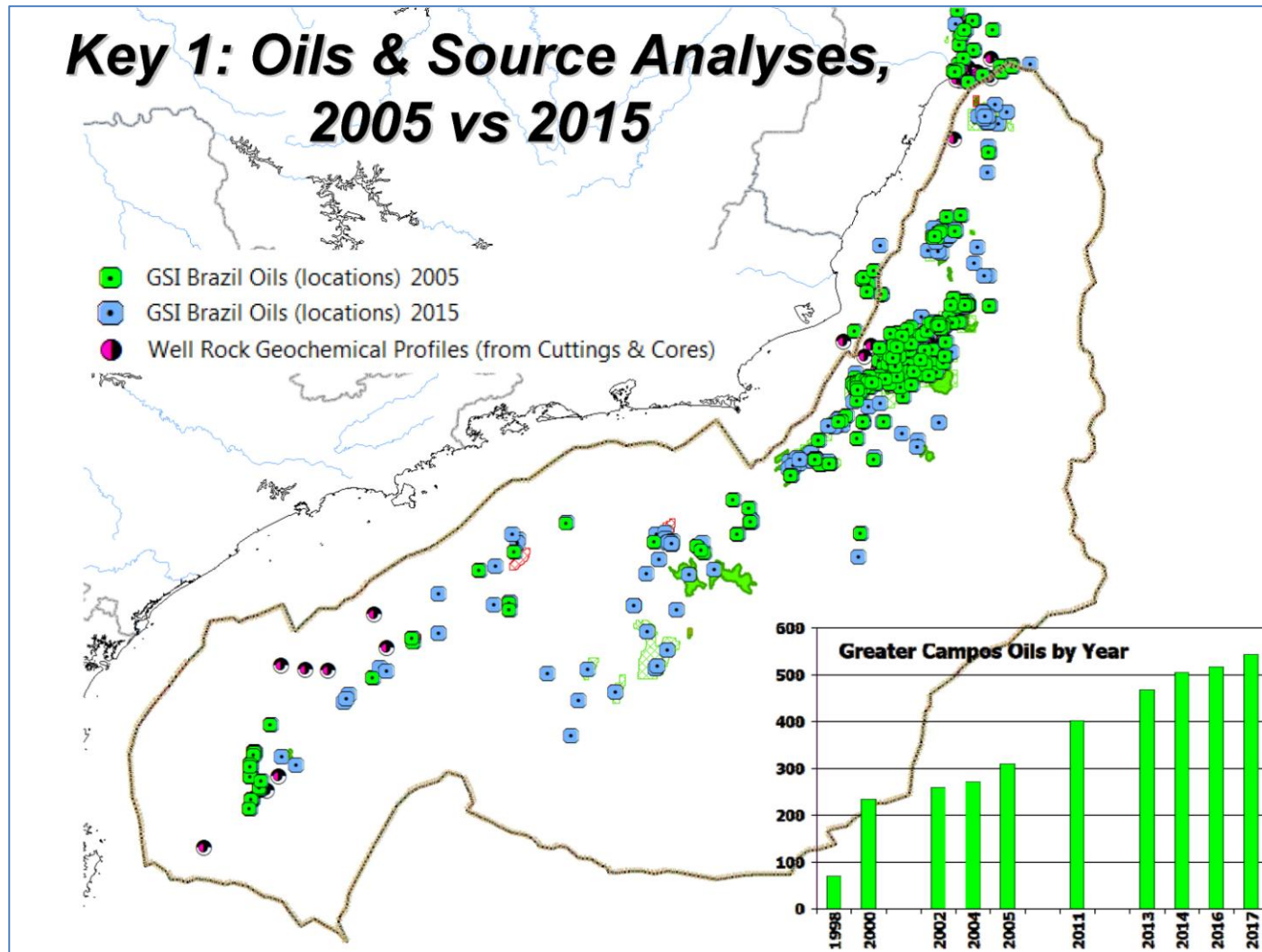
Presenter's notes: Two reasons to hesitate: Campos was working big and Santos was small & gas-prone. By analogy to the Campos pre-salt source, Santos stratigraphy had a similar time-equivalent interval, the Guaritiba which was modeled for maturity through time. Above is Chang (2003) Present-Day (0 Ma) maturity for the Santos Basin axis and immediate flanks, overlaid on MARIMBA gravity isostatic residual anomaly. Central maturity fairway (orange-red) along basin axis is over-mature for gas. Circled producing fields as of 2005 naturally bias towards gas/light oil.



Presenter's notes: 2005 Giant oil production in the Campos Basin from post-salt reservoirs, mainly sourced from pre-salt lacustrine source rocks. Minor oil and gas production in Santos from post-salt reservoirs, believed mainly sourced from post-salt marine source rocks (Itajai-Acu). Conventional wisdom discounted pre-salt potential despite solid work by Pereira and Macedo (1990), and Chang (2003) highlighting pre-salt source potential; two majors had relinquished their Santos positions.



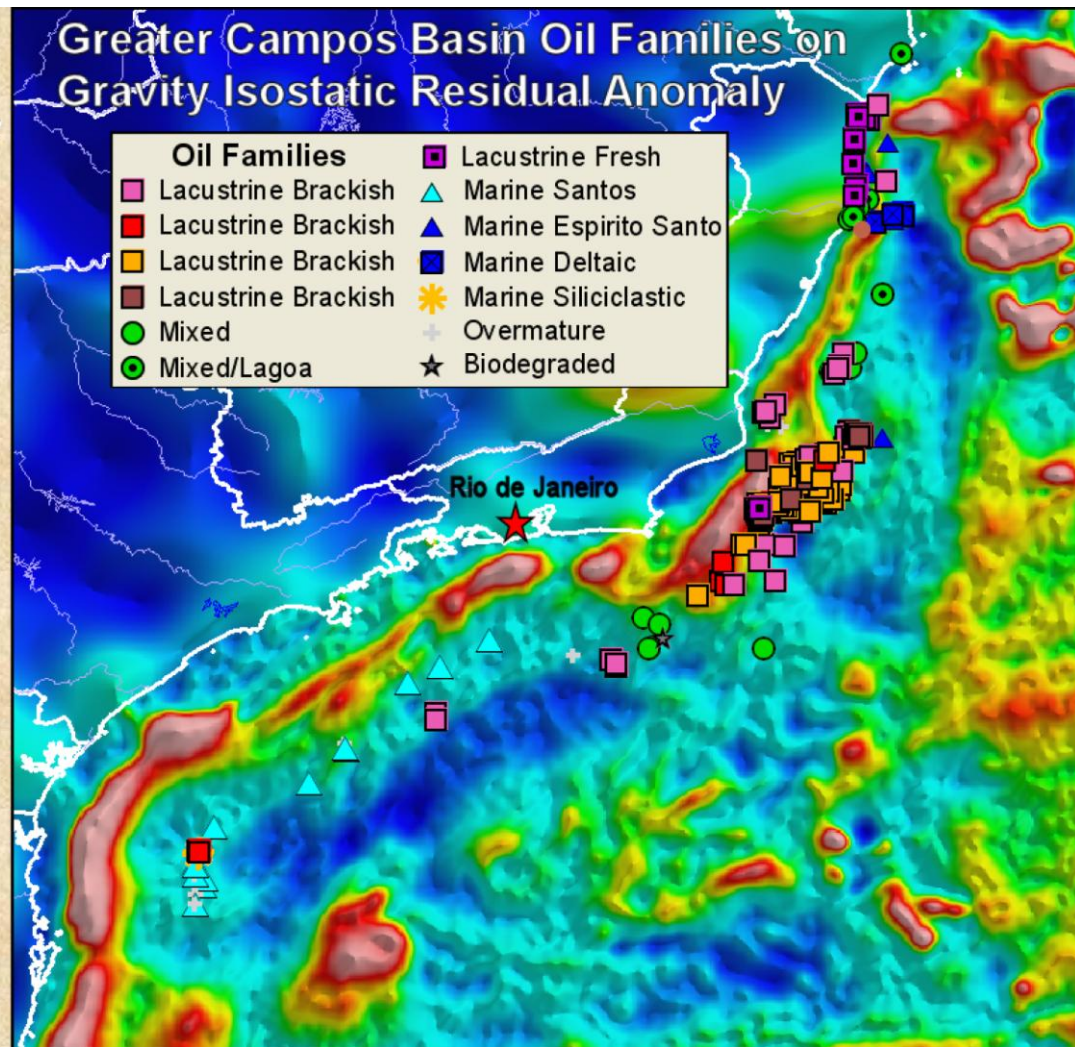
Presenter's notes: 2017 Giant oil production in the Campos Basin from post-salt reservoirs and increasing production from pre-salt reservoirs, mainly sourced from pre-salt lacustrine source rocks. Infrastructure enabled pre-salt development via tie-backs and deeper target reuse of platform slots. Super-giant discoveries in Santos Basin with pre-salt reservoirs under development. Somewhat increased oil and gas production from post-salt reservoirs, dual sourced from post-salt marine and pre-salt sag to lacustrine source rocks. What changed? A structure too big not to drill resulted in the Tupi discovery (T), now Lula Field in late 2006, followed by Franco (F), and Libra (L), each 5+ billion bbl recoverable!



Presenter's notes: Our database as of 2005 contained oils and cuttings samples from proximal wells. By 2015, the number of oil samples had almost doubled over a greatly enlarged area and including 30 pre-salt tests. This altered our initial evaluation while supporting the key 2005 insight of basin-wide pre-salt sourcing from the Guaritiba (Lagoa Feia equivalent).

## ***Oil Families: 2005***

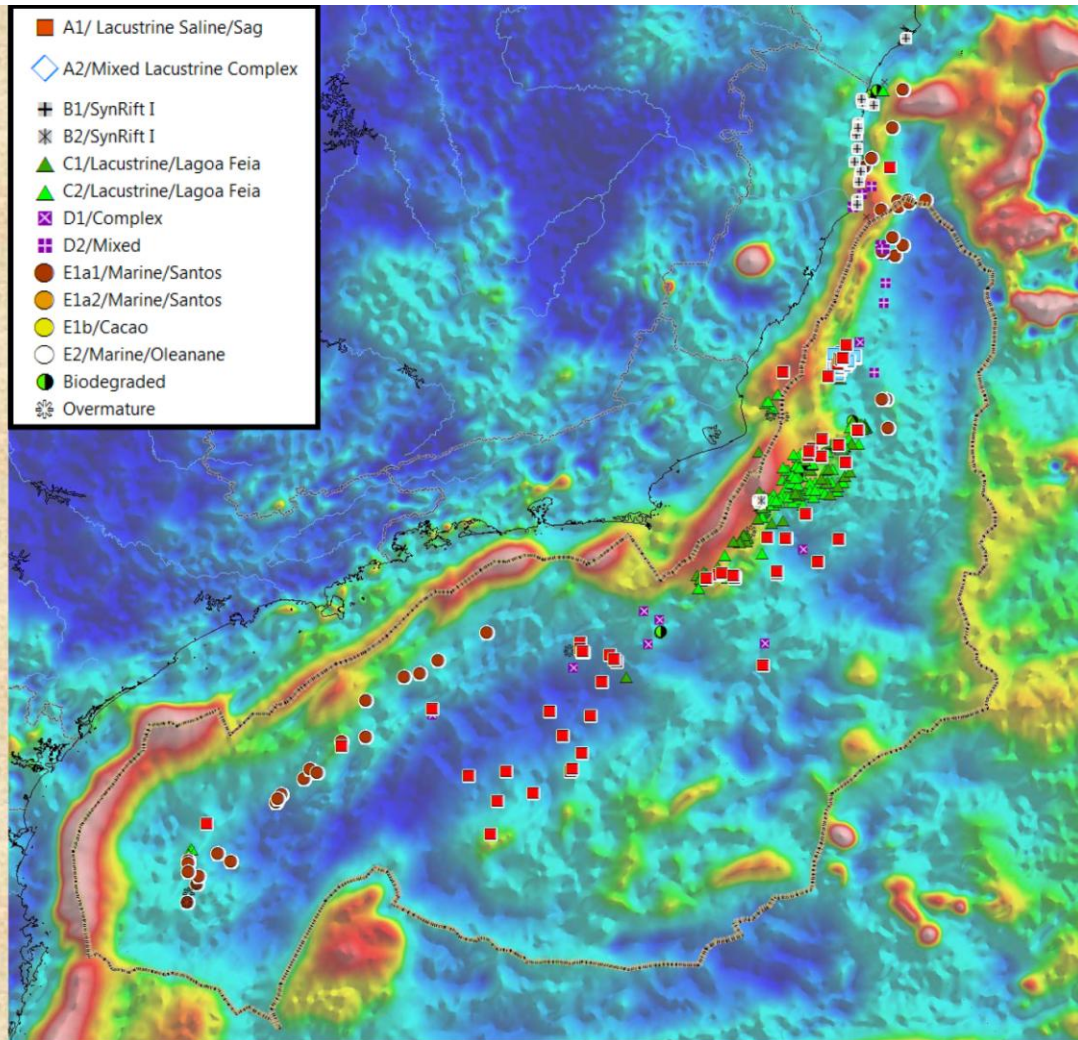
~300 oils could be grouped into Marine & Lacustrine families with some (Green Circles) exhibiting both components



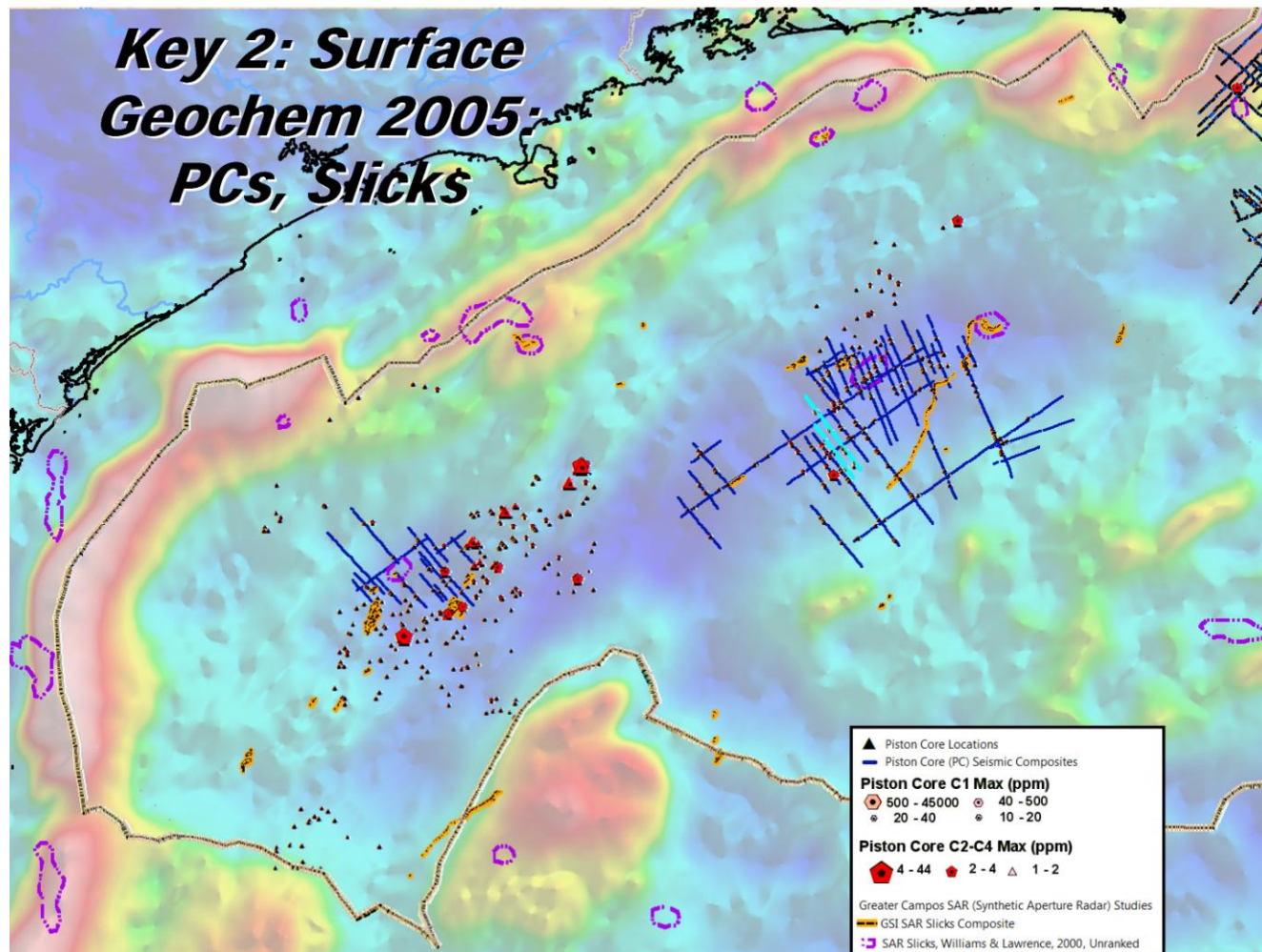
Presenter's notes: Only a handful of samples in the Santos proper (southwest of CaboFrio) contained indications of pre-salt sourcing. On their own, insufficient to confirm our contention of basin-wide pre-salt sourcing but enough to spur the search for confirmation.

# ***Oil Families 2015 on Gravity Isostatic***

505 oils are grouped into Lacustrine, Sag (both pre-salt) and Marine (post-salt) families. Purple squares exhibit both Marine & Lacustrine components



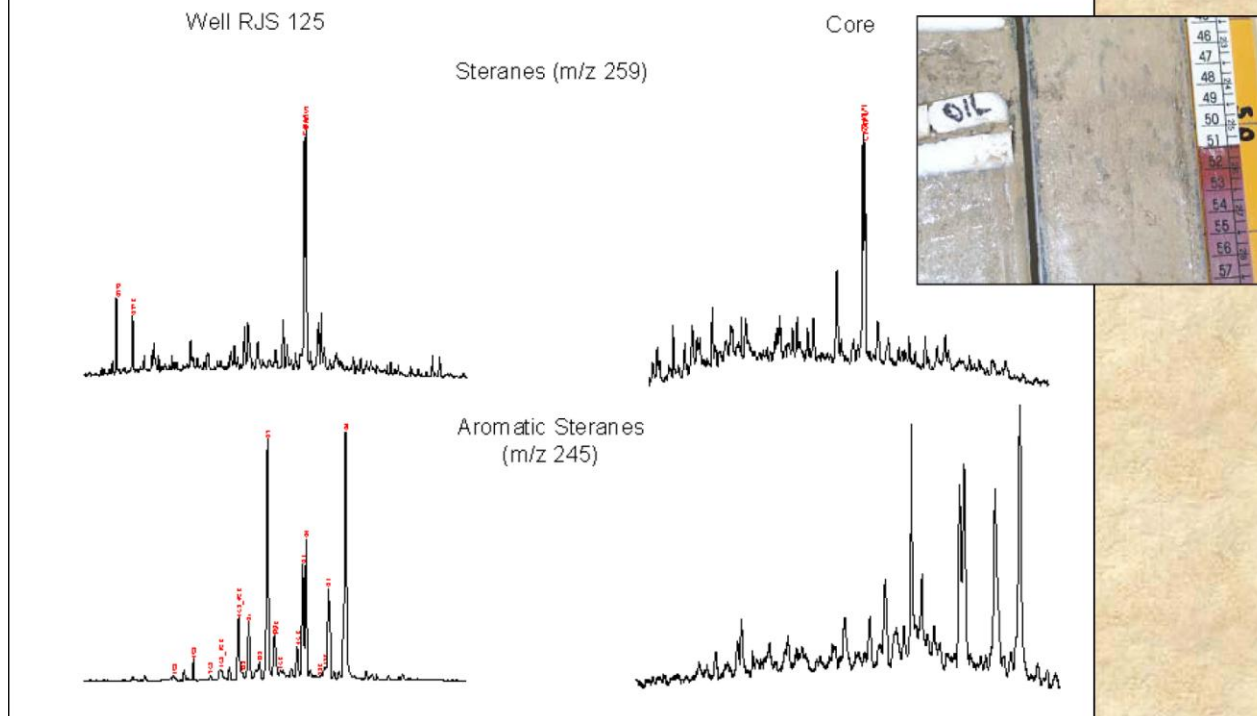
Presenter's notes: Many more oils from pre-salt tests which verified our hypothesis of pre-salt sourcing. Key take-away: widespread pre-salt Sag family indicates a uniform paleo-environment from southwestern Santos to southern Espirito Santo, about 1300 km! The Sag source appears to be transitional so we infer alternating or interbedded layers of marine and lacustrine-influenced organic material as the basin gradually became marine.



Presenter's notes: Surface geochemistry provided three keys to our insight: First, a key piston core collected in southwestern Santos sampled a macro-seep typed to a lacustrine source (see next slide); and lying beyond the basin axis, it sampled a more distal location than any existing wells. Second and Third, SAR slicks distribution and intensity illuminated migration range and seal failure type (refer to following slides). Note multiple SAR slicks all around the basin periphery suggesting a loss of top seal only or mostly at the basin margin.

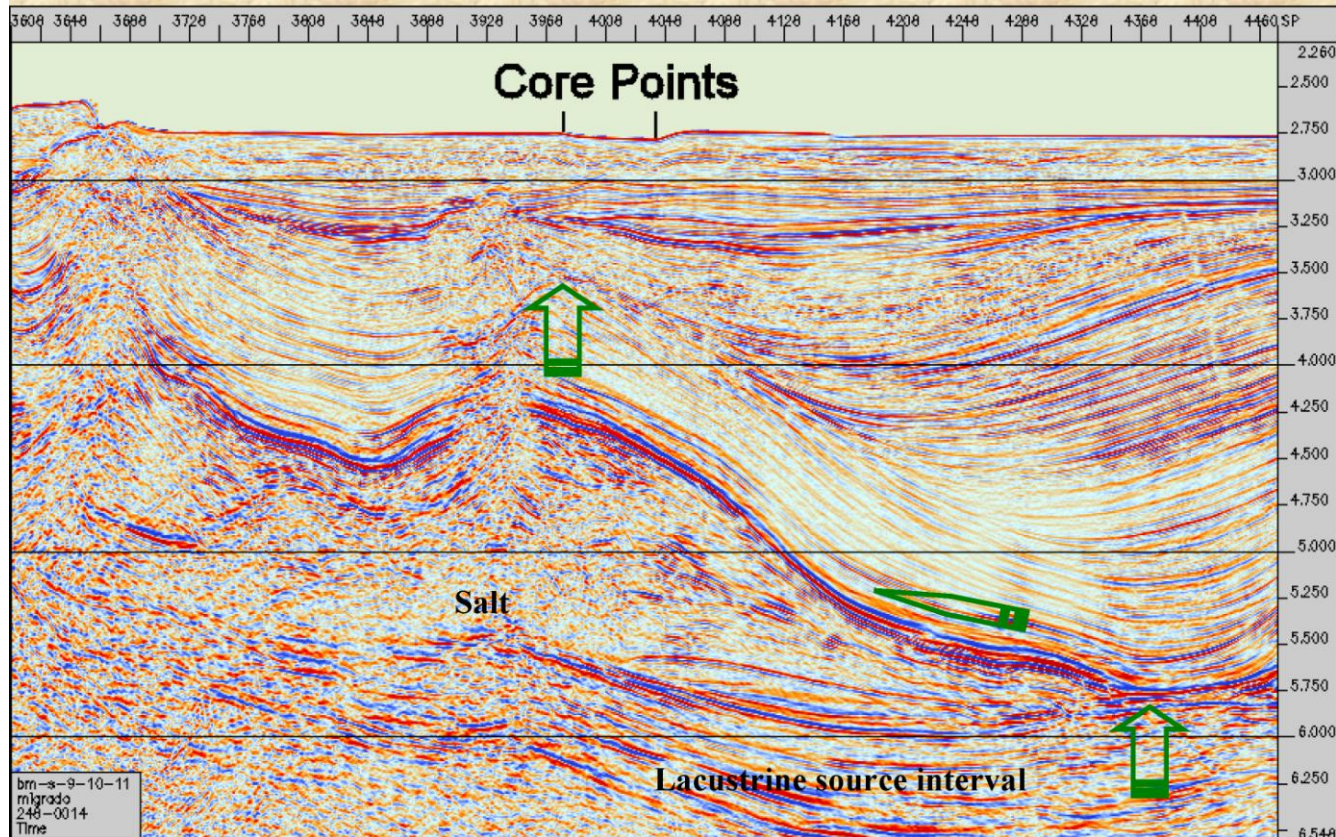
## ***Seep (R) matches RJS-125 lacustrine oil (L)***

### Comparison of Biomarkers in "Macroseep" and Lacustrine Oil

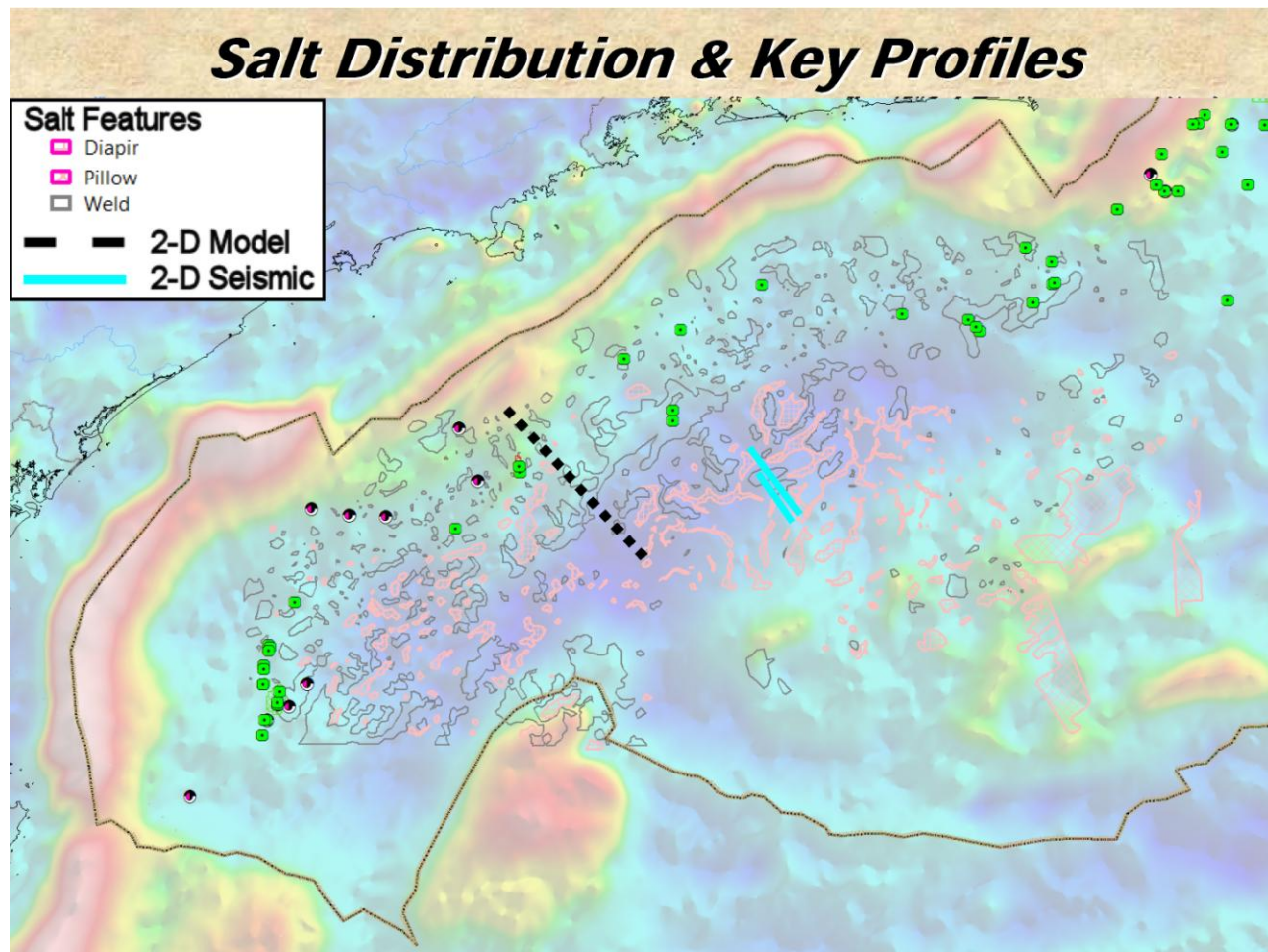


Presenter's notes: Chemical attributes of this key piston core macro-seep were consistent with a lacustrine origin. At the time (1999), this seep represented the first positive indication of an active lacustrine source in southwestern Santos because available 'black oil' samples (ie, 'topped' samples with only C15 and heavier compounds remaining) appeared to be marine derived. Later analysis of diamondoid compounds from a few whole oils (i.e. containing the full range of compounds from C6+ and thus the diamondoid range) gave evidence of a minority contribution from a lacustrine source along with the marine-dominated black-oil fraction. Hence, this piston core macro-seep had an equivalent value to a pre-salt oil discovery because it demonstrated a lacustrine affinity.

# ***How Hydrocarbons Escape: Salt-related Migration Paths***

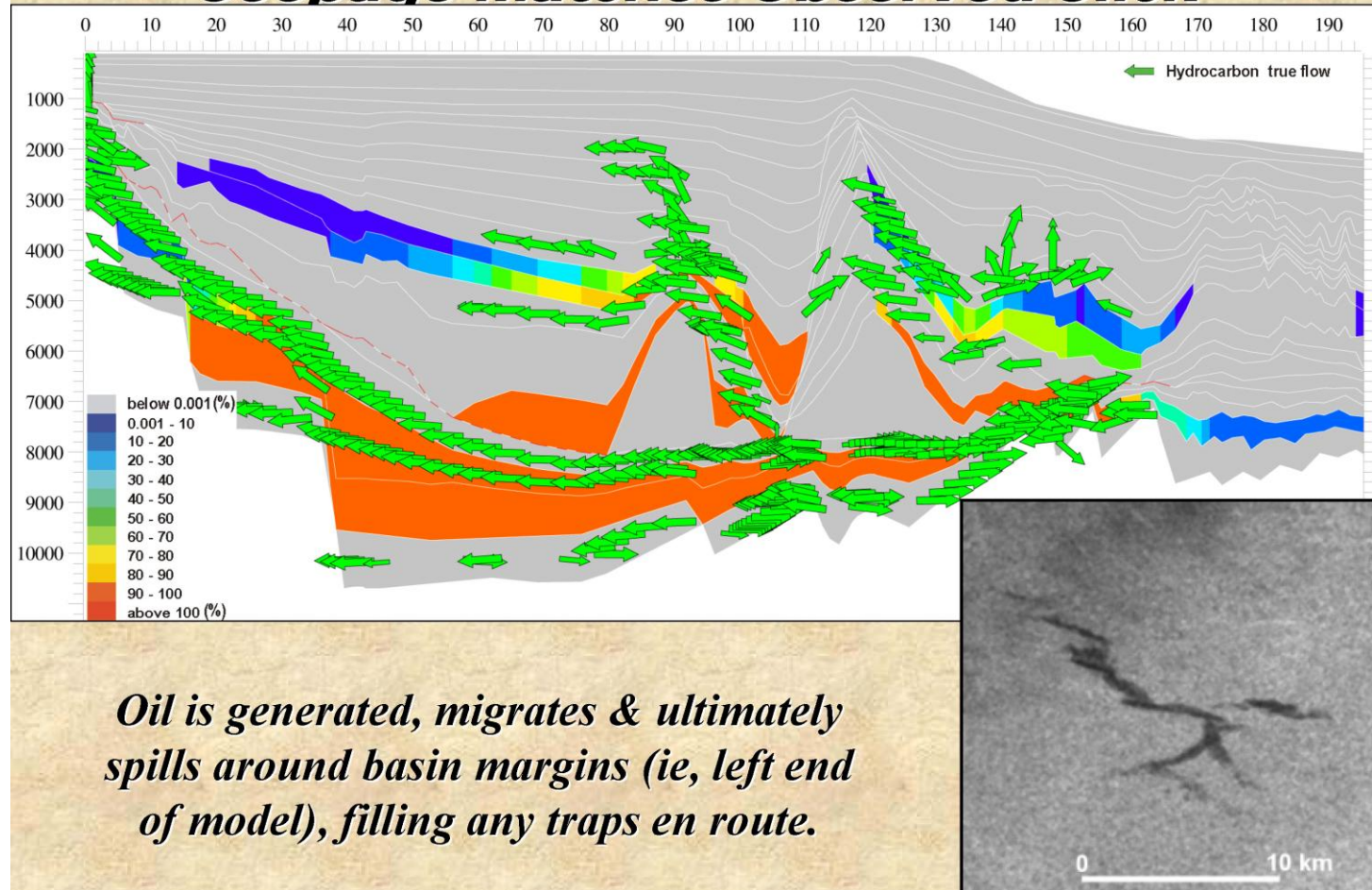


Presenter's notes: In professional ice hockey, a N-S game means always driving to the net. An E-W game is one of constant ball movement that creates openings. The strongest teams combine both NS & EW games. Similarly, migration here is first vertical (hydrocarbons are directionally biased by buoyancy, only, as it were, going N) from pre-salt lacustrine source across a salt weld/ evaporite thin into post-salt carrier beds. Then horizontal (E-W) migration follows post-salt carrier beds until reaching salt piercements/evaporite thicks where the top seal is disrupted, allowing escape (N again!) to the surface.



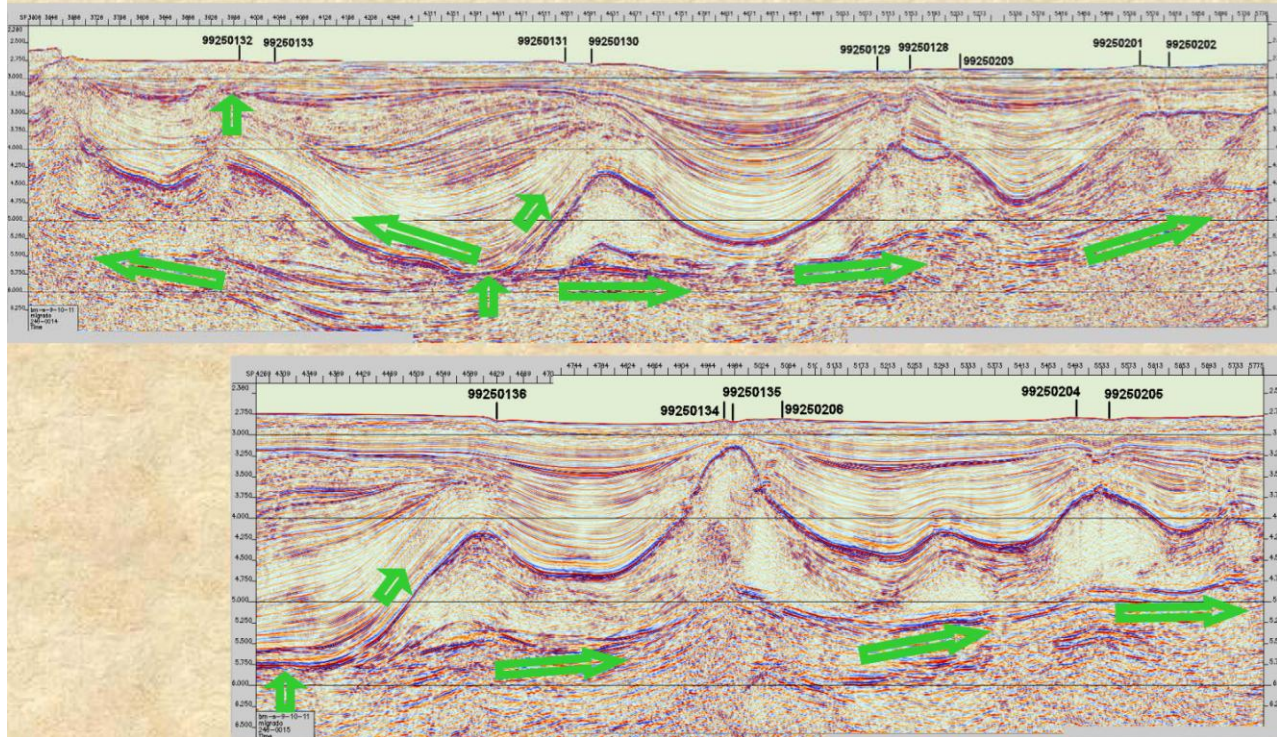
Presenter's notes: Black dashed line is a 2-D Temispak®Model based on a published profile (Cainelli and Mohriak, 1998, Figure 6; Chang, 2003; Chang et al., 1992). For modeling purposes, only the northwestern-most 195 km of the as published original seismic line have been used. The pair of aqua-coloured lines are seismic composites shown on slides 20 & 23. Salt distribution (diapirs, pillows and welds) taken primarily from Modica & Brush, 2004; augmented from a score of other publications. Thicker evaporites (salt diapirs) disrupt the top seal allowing leakage to the sea floor where they are detected by SGE (seeps) and SAR (slicks) methods. Salt welds provide escape paths for pre-salt hydrocarbons into the post-salt sequences.

# ***Modeled Maturity & Charge/Migration: Seepage Matches Observed Slick***



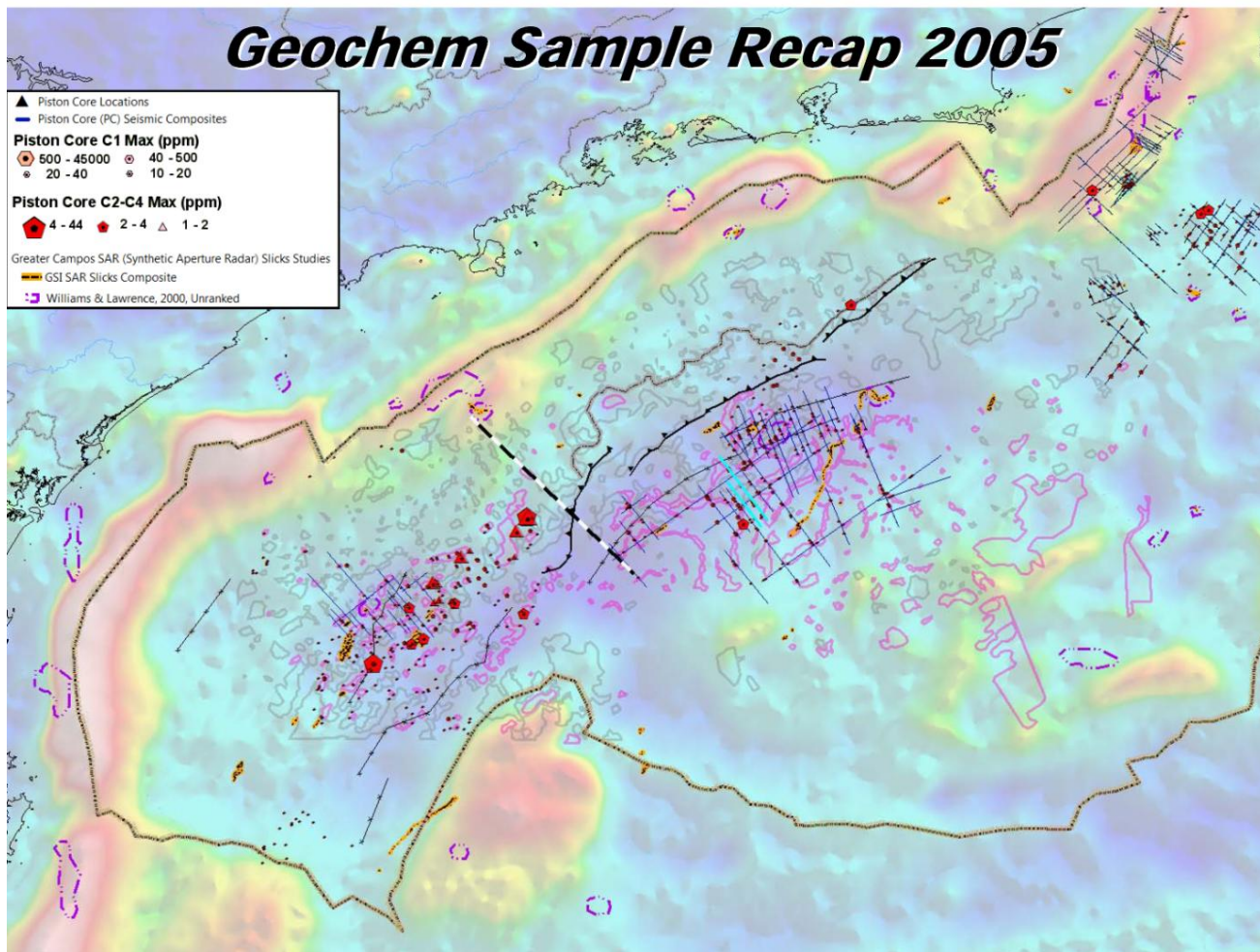
Presenter's notes: The observed SAR slick (lower right SAR image) corresponds to seep location at upper left of model.  
Coincidence? –we think not!

## ***Where, How Far do HCs go?***



***Sediment isopach inadequate to the SE (right) for maturity of the post-salt source;  
basin-margin seeps require sub-salt migration!***

Presenter's notes: With an impervious salt layer (as on regional seismic composite profiles above) providing a barrier to vertical migration, the 2-D model (previous slide) predicted long-distance lateral migration to the basin margin before oil escaped vertically. A SAR study confidently identified seepage within the basin and, at lower confidence, dispersed seepage along the margins. Localized maturity of the post-salt Itajai-Acu source meant no expulsion paths existed from mature Itajai-Acu to the distal (south and southeast) basin margin. Only lateral migration below the salt could reach the margins. This also requires fill-to-spill of any pre-salt traps before excess hydrocarbons escape.

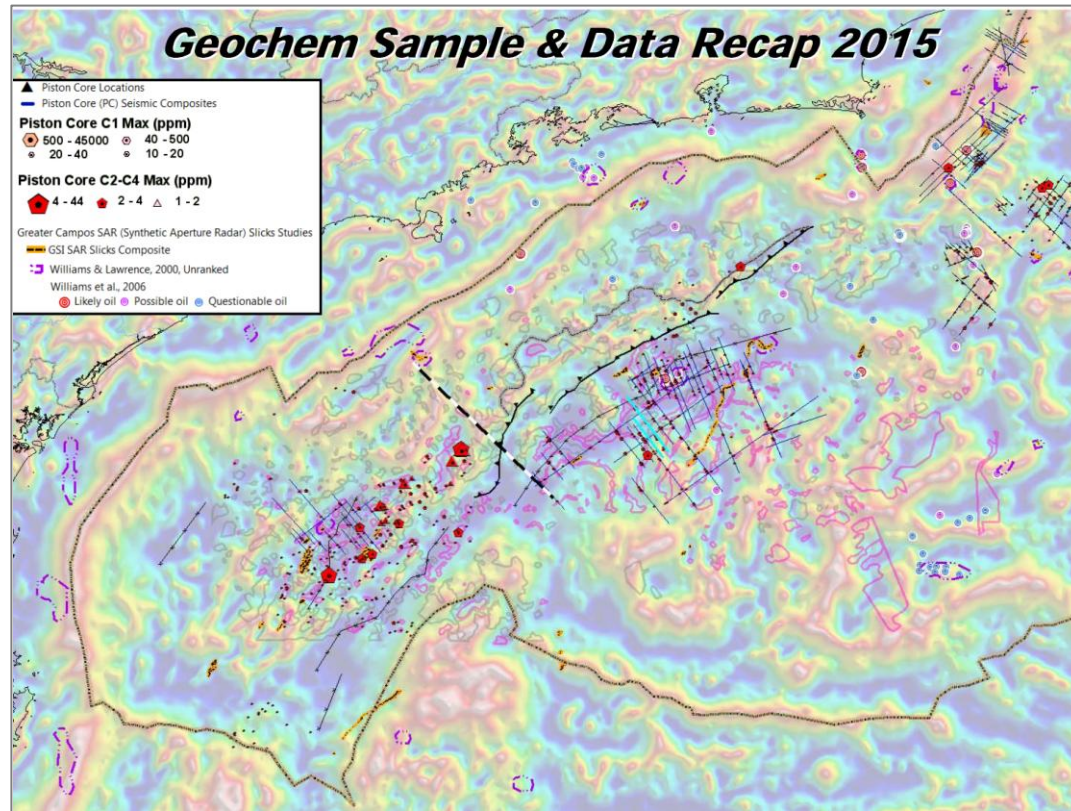


Presenter's notes: 2005: A complete story from a statistically small number of variegated samples:

- About 300 oils in proximal locations with scant evidence for a lacustrine (= pre-salt) contribution, partially due to sample 'topping' per slide 19.
- Evidence of escaping hydrocarbons in few piston cores but including a key macro-seep that typed to a lacustrine source.
- SAR slicks from two studies (GSI plus a publication by Williams & Lawrence) - higher quality in sub-basin centers associated with salt pillows and diapirs.
- More slicks but of lower confidence around basin margin

## ***Santos Conclusions, 2005***

- Evidence of presalt sourcing from careful analysis of a few outliers in reservoired oils, piston cores
- Support came from understanding possible migration pathways (kitchen to escape) via basin modelling, seismic, slicks.
- Piston core seep intensity relates to salt shapes; infer larger reserves in Santos NE, smaller in SW



Presenter's notes: 2017 versus 2005: Driving home the original hypothesis of pre-salt sourcing and recognition of a basinwide pre-salt 'sag' facies association:

- Many more oils (505 vs. ~300) with first (~30) direct sampling from pre-salt reservoirs sitting outboard of the basin axis.
- Acquisition of Deuterium (D2) isotopes for all Greater Campos and most other oils to indicate marine vs. lacustrine affinity.
- Infill analysis of aromatic biomarkers (source affinity indicators) and diamondoids (thermally the most stable components of any hydrocarbon with significance for source, thermal and migration histories).
- Added SAR interpretation points from Williams & Lawrence, 2006.
- Expanded and updated piston core interpretations.
- Much-improved potential field compilations. Background of above image is GI-AGC (Gravity Isostatic AGC) from May 2014 recompilation demonstrating higher structural resolution. Whole oil deuterium isotope values less negative than ~ -110 permil suggest a lacustrine origin, while values more negative than -110 ('heavy') originate from source rocks deposited in a marine environment.

## ***Santos Conclusions, 2015***

- Examine whole oil, not just black oil (C15+) component
- Analyse the works:
  - D2 (deuterium isotopes)
  - aromatic biomarkers & diamondoids
- Pre-salt *Sag* source is present basin-wide
- Keep digging – there's more to learn!

## ***Last Thoughts 1: Use Tools to Fit the Task***

- Tools: Remote sensing, Geochem, G&G Analysis, Basin Modeling
- Clues: Piston cores, Crude oils, Slicks, Source rocks, Sediment isopach, Basement shape

Regional  
Gravity, Oils,  
Basin Model  
6-100 km

2D Seismic,  
Detail G&M,  
Radarsat slicks  
1-5 km

3D Seismic,  
Piston cores,  
Borehole G  
10-100 m

## ***Last Thoughts 2: Using the Tools***

- Review entire basin
- Combining tools, data --> value but beware *caveats*
- Small team advantage – no silos
- Work, rework, repeat

# ***Project History and Acknowledgements***

## **Project History**

- from collaborating on a 2001 paper for an AAPG Hedberg Research conference, the authors developed a concept of basin-wide sourcing of a pre-salt play in Brazil's Santos Basin.
- milestones included presentations at AAPG conferences in 2004 (Cancun), Calgary (2005), San Antonio (2008) and Rio de Janeiro (2009)
- the 2005 poster demonstrated our evidence, data from multiple disciplines and sources
- a series of super-giant discoveries from 2006 - 2012 validated our source story
- for AAPG 2017, we updated the 2005 poster in a what-we-knew-then versus what our current expanded database reveals

## **Acknowledgements**

- All potential field data presented in this paper are licensed to DIGs by the compiler Grizzly Geosciences whose untiring efforts have produced material essential to our interpretations.