Otway Stage 4 CCS Project

Recharacterization of the Tidal Depositional System for Parasequence 2 of the Paaratte Fm, Australia

Dr. Nadine Pearson and Ishtar Barranco
Chevron Technology Center
March 3, 2025

Acknowledgements
Laura Gomez, Andy Wilson, Luca Duranti, David Bason, Genna Petho, Chuck Pillow, Jaime Mercado, Matthew Mercado, James Meyer, Pete Sixsmith, Lawrence Febo

Recharacterization of the Tidal Depositional System for Parasequence 2 of the Paaratte Fm, Australia

Outline

- Introduction
- Field Location
- CO2CRC Pre-GFV Injection Depositional Model
- CRC-8 Parasequence 2
  - *Chevron facies interpretation*
- CRC-3 Injection Well
  - *Injection zone facies interpretation*
  - *Gas injectivity and capturing the range of geological uncertainty*
- CRC-8 Monitoring Well
  - *'Predicted' arrival zone facies interpretation*
- Regional Cross-Section
- Inquiries and Ongoing Work
- Why does it matter?

What did we do?

1. **Re-examined and integrated multiple lines of geological & paleontological data acquired into a revised interpretation for the tidal deltaic depositional system**
   - Included data: Core, CT images, FE, image logs, and routine core analysis (RCA)
2. **Described and defined the heterolithic depofacies – NEW!!**
   – Delta front broken into proximal and distal delta front, and prodelta
   – Coastal plain included and subdivided into crevasse splay delta and bay fill
3. **Leveraged stratigraphic correlation to predict expected CO_2 arrival zone – NEW!!**
   – At CRC-3, CO_2 was injected into crevasse splay delta lobes, interdistributary bay fills, and proximal delta front facies
   – At CRC-8, 116m away, similar depositional facies are found in the monitoring well in an up-dip position
4. **Leveraged depositional facies characteristics to predict expected CO2 injection connectivity and quality – NEW!!**
   – AT CRC-3, CO_2 was proposed to be injected into a 'tight, heterolithic zone', Kh values from RCA in the injection depofacies show higher than expected values than those taken from initial log values, predict better CO_2 injection

Why?

The GFV project's CO2 migration testing infrastructure and time-lapse database provides validation to methodologies delineating fine-scale reservoir heterogeneity in reservoir and simulation models, an essential pre-requisite for confident predictions of CO2 storage, enabling effective site investment, risk management, and site closure decisions.

CO2CRC (Who are we?)

21 years of proven and successful CCS

At scale investment – Long-term infrastructure and RD&D funding ($200M+)

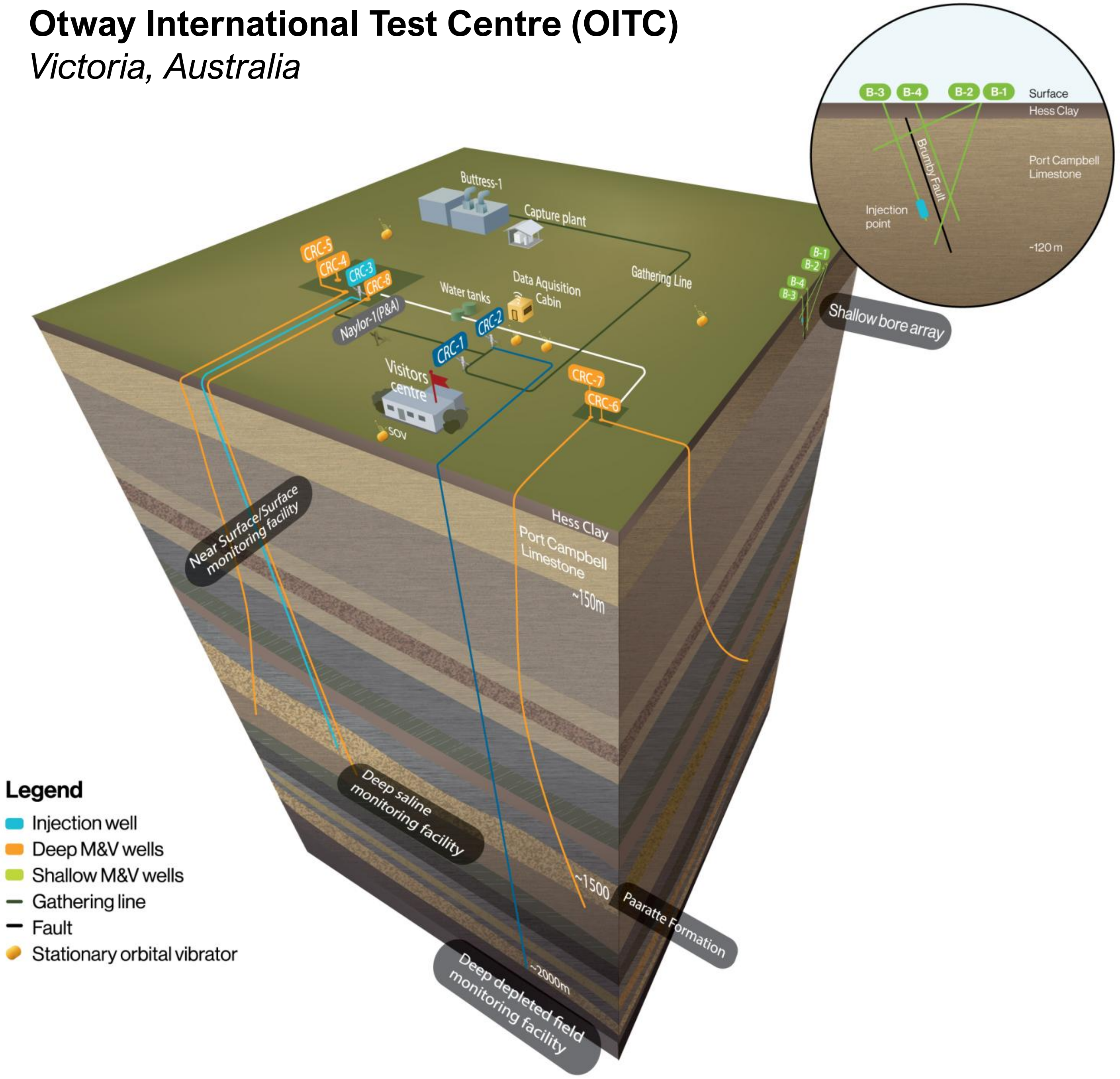
Focused on **accelerating Australia's transition to a low emissions future**

Industry-led Research, unique, real project data

Well-established **collaboration** between universities, industry, nationally and internationally

Globally unique test centre (OITC) **to accelerate development and commercial deployment** of technologies

Otway International Test Centre (OITC)
Victoria, Australia



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Building a low emissions future

Otway Stage 4

Demonstrate commercially focused reservoir management technologies to improve injection, storage and monitoring efficiencies, and materially lower costs for CO_2 storage projects

Objectives

- Improve modelling workflows to effectively support operations and closure
- Provide >20% increase in CO_2 storage efficiency for commercial storage
- Develop fit-for-purpose storge 'performance' M&V technologies

Technologies

- GeoCquest Field Validation (GFV) Project
- Distributed Strain Sensing
- Seismic M&V
- Surfactants
- Micro-Bubble Injection

Funders

Chevron, BHP, bp, ExxonMobil, LETA Low Emission Technology Australia, Australian Government Department of Climate Change, Energy, the Environment and Water

Research Partners

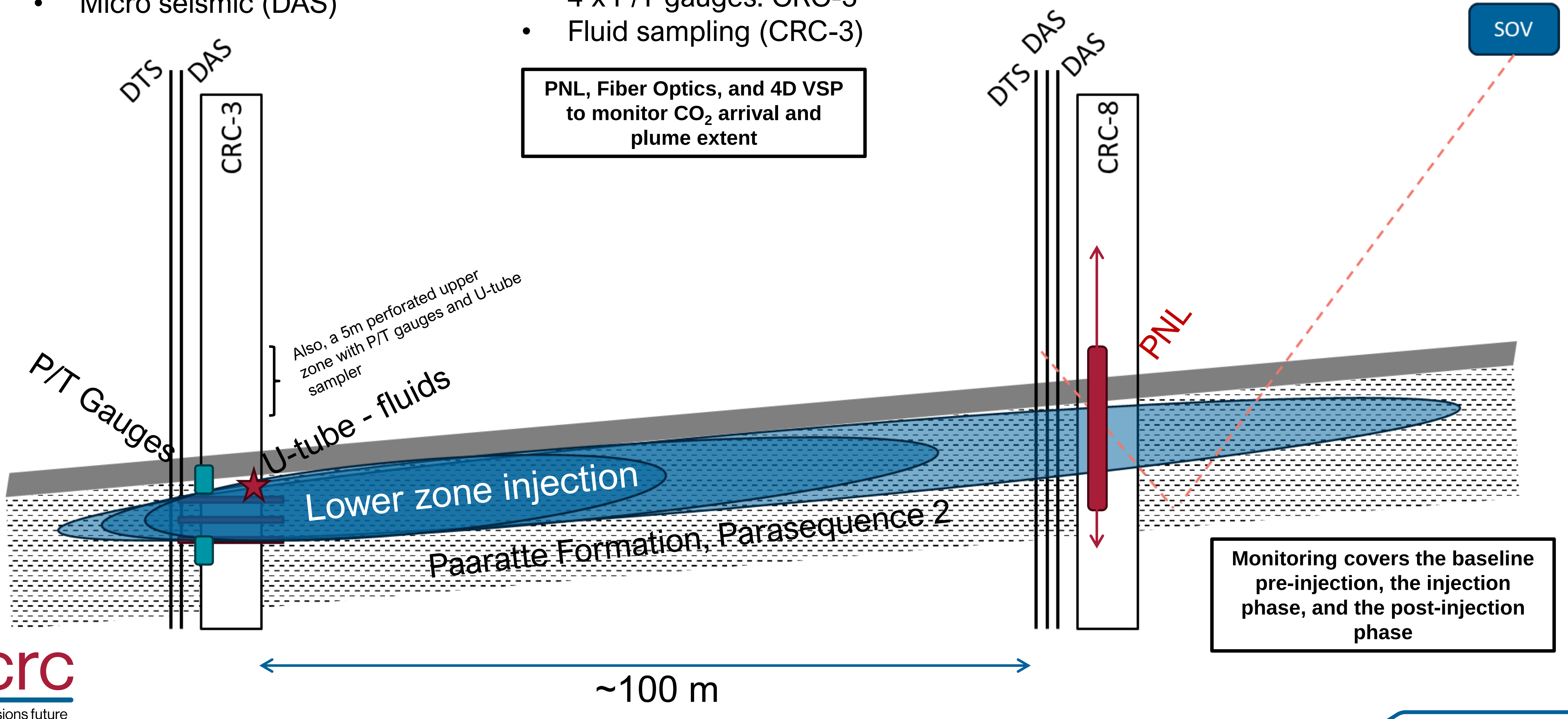
RITE Research Institute of Innovative Technology for the Earth, Stanford University, Curtin University, The University of Melbourne, KIGAM Korea Institute of Geoscience and Mineral Resources, Berkeley Lab, Australian Government Geoscience Australia

GeoCquest Field Validation Experiment

Whole of Reservoir
- 2D VSP (DAS + SOV)
- 3 x 3D VSP (DAS + Vibroseis)
- Micro seismic (DAS)

Near Well
- F/O for DTS (+DSS in CRC-8)
- Repeat Saturation Logging (PNL)
- 4 x P/T gauges: CRC-3
- Fluid sampling (CRC-3)

PNL, Fiber Optics, and 4D VSP to monitor CO_2 arrival and plume extent



Monitoring covers the baseline pre-injection, the injection phase, and the post-injection phase

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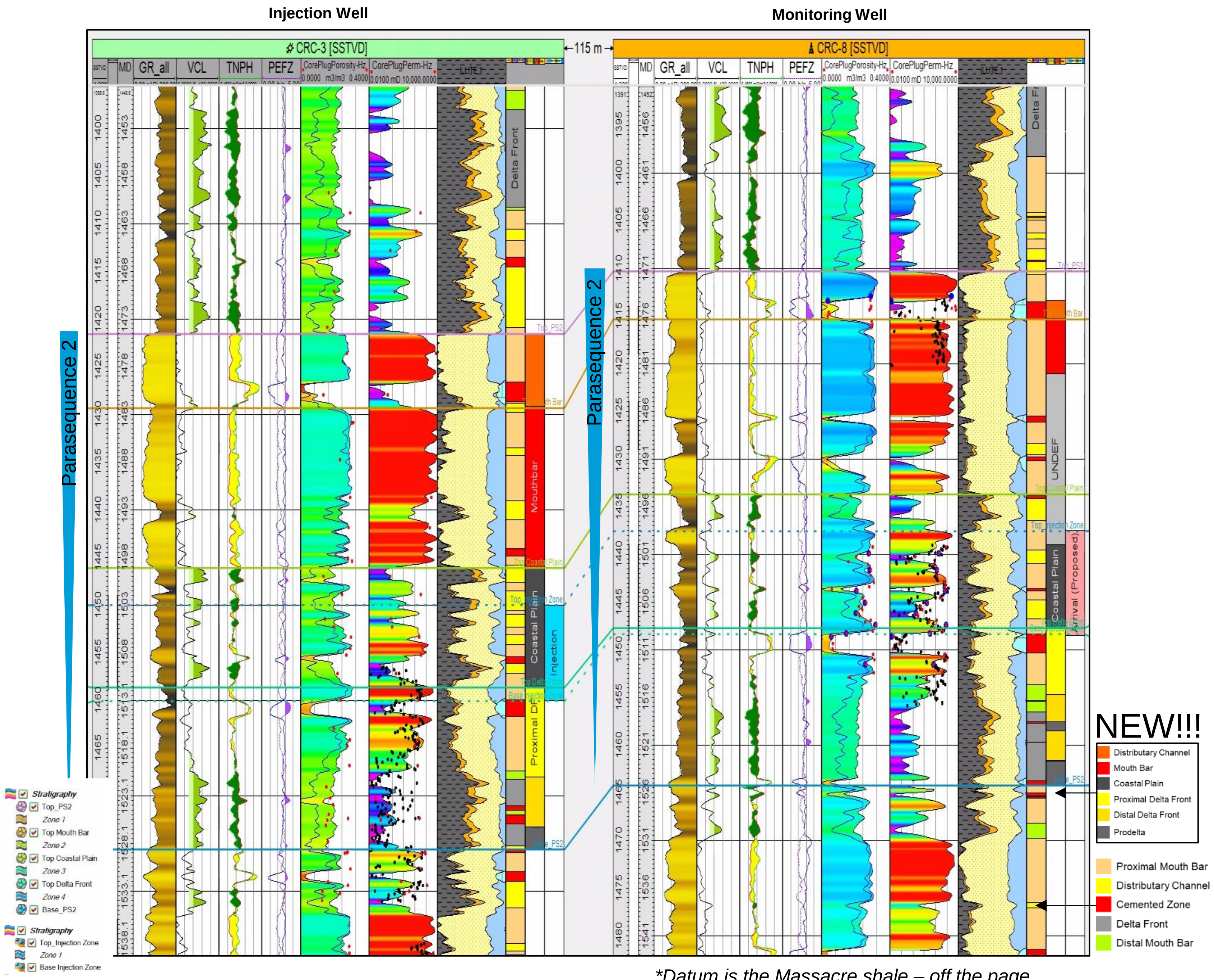
Recharacterization of the tidal depositional system



Datum is the Massacre shale – off the page

It takes a team of people, so involve the right people early on in your assessment

- Geologists
  - Tidal sedimentologist and ichnologist
  - FMI specialist
- Geophysicists
- Engineers
- Researchers
  - CO_2CRC

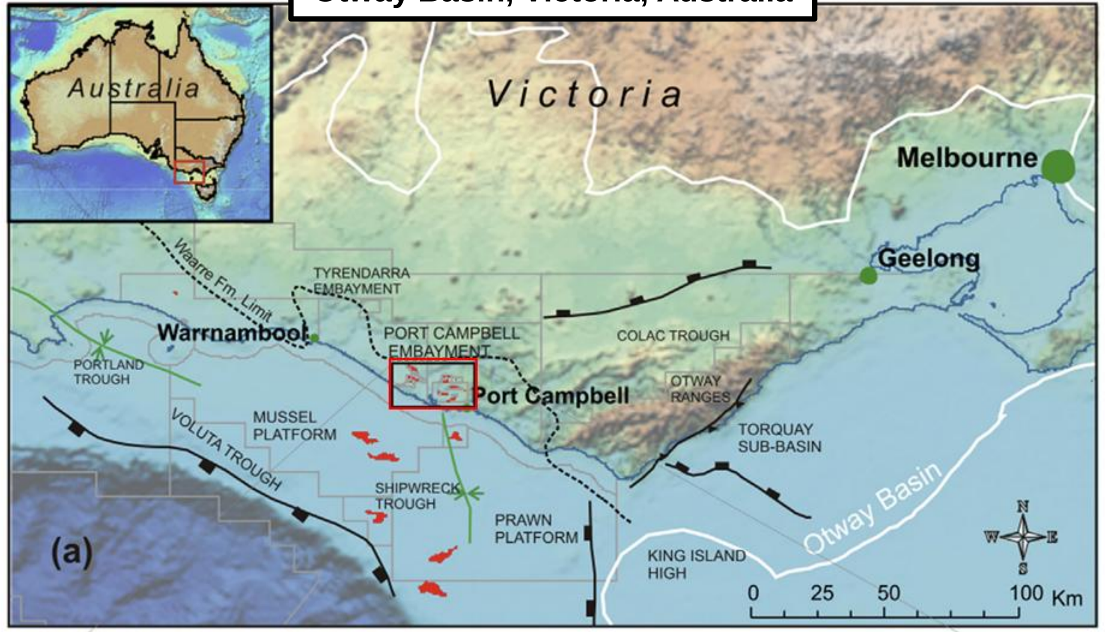
It is important to incorporate and integrate ALL the available data into any geological model – <u>*work ongoing*</u>

- Formation evaluation
  - Understand what the FE data is telling you
- Core and CT scans
  - Sedimentological data
  - Ichnological data
- Image logs
- Routine core analysis
- Depofacies stacking patterns and stratigraphic significance
- *More to come…e.g., seismic, palynology, arrival data, saturation, fault interaction, etc.*

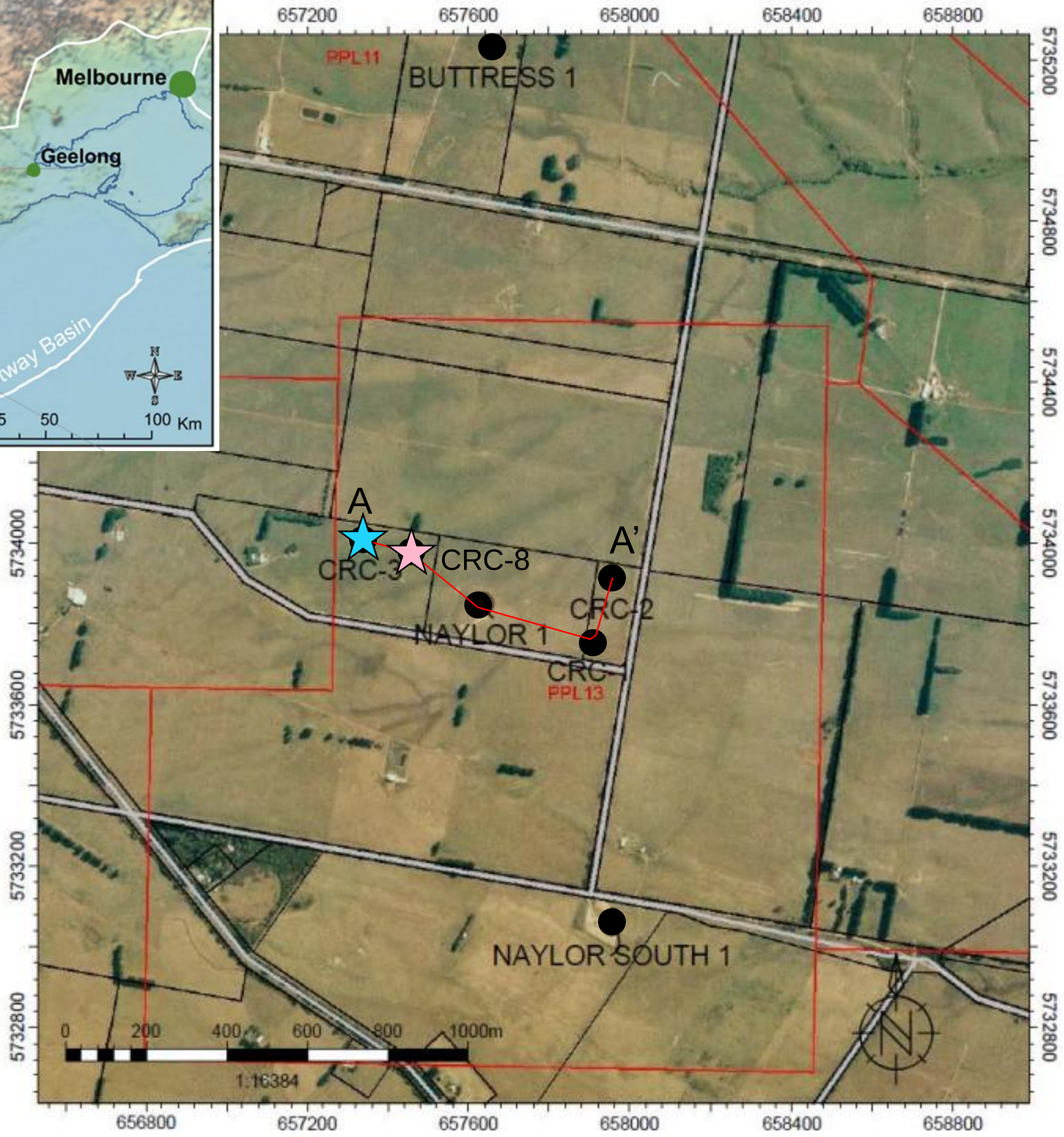
CO2CRC Otway Project

Field location

Otway Basin, Victoria, Australia



Dance, 2013

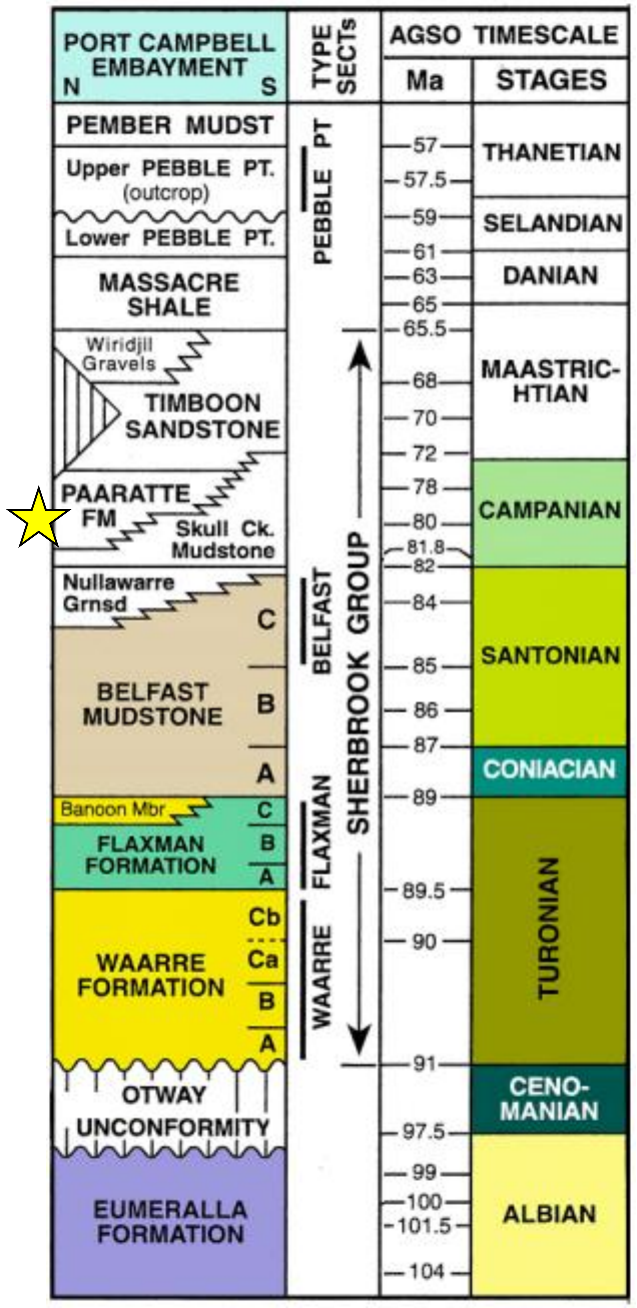


The Paaratte Fm was deposited as shallow-marine, deltaic sediment building out into the Shipwreck Trough, the offshore extension of the Port Campbell Embayment, during the later stage of rifting and extension in the Otway Basin's history (Krassey, 2004; Dance and Glubokovskikh, 2017)

CRC-3 Injection Well

CRC-8 Monitoring Well

Lithostratigraphic column of sedimentary units in the Port Cambell Embayment



Dance, 2013; Partridge, 2001

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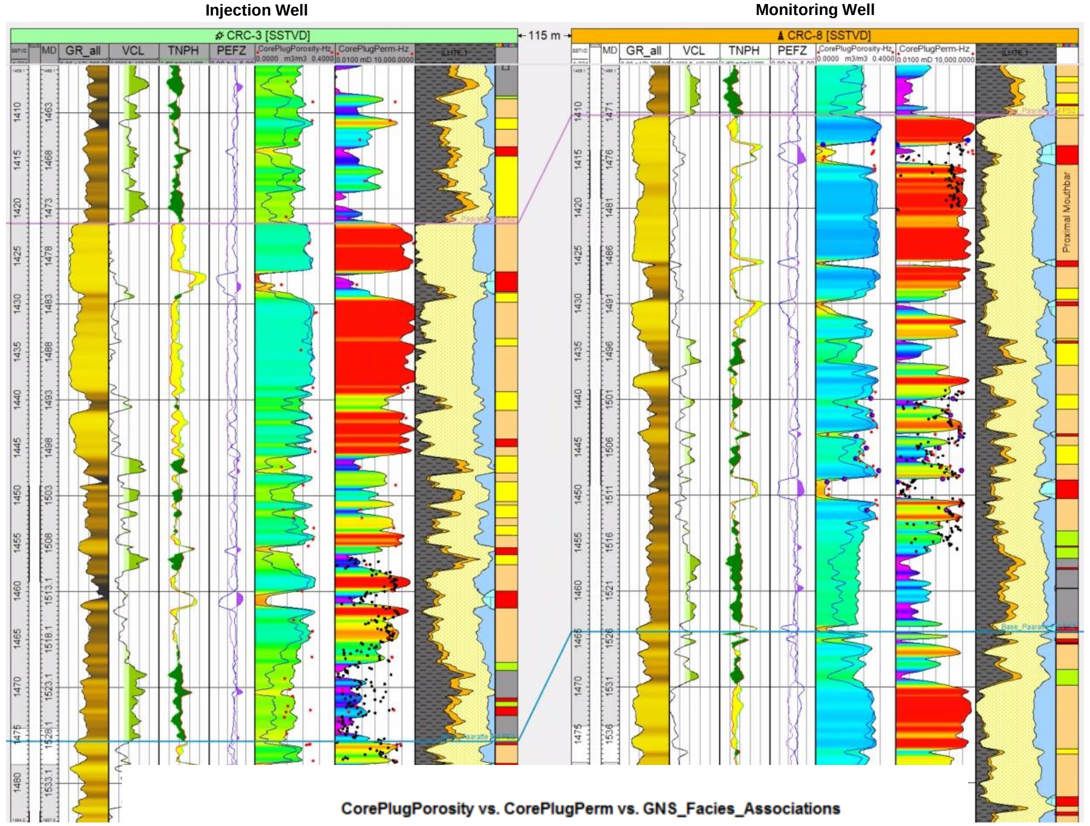
CO2CRC Pre-GFV Injection Depositional Model

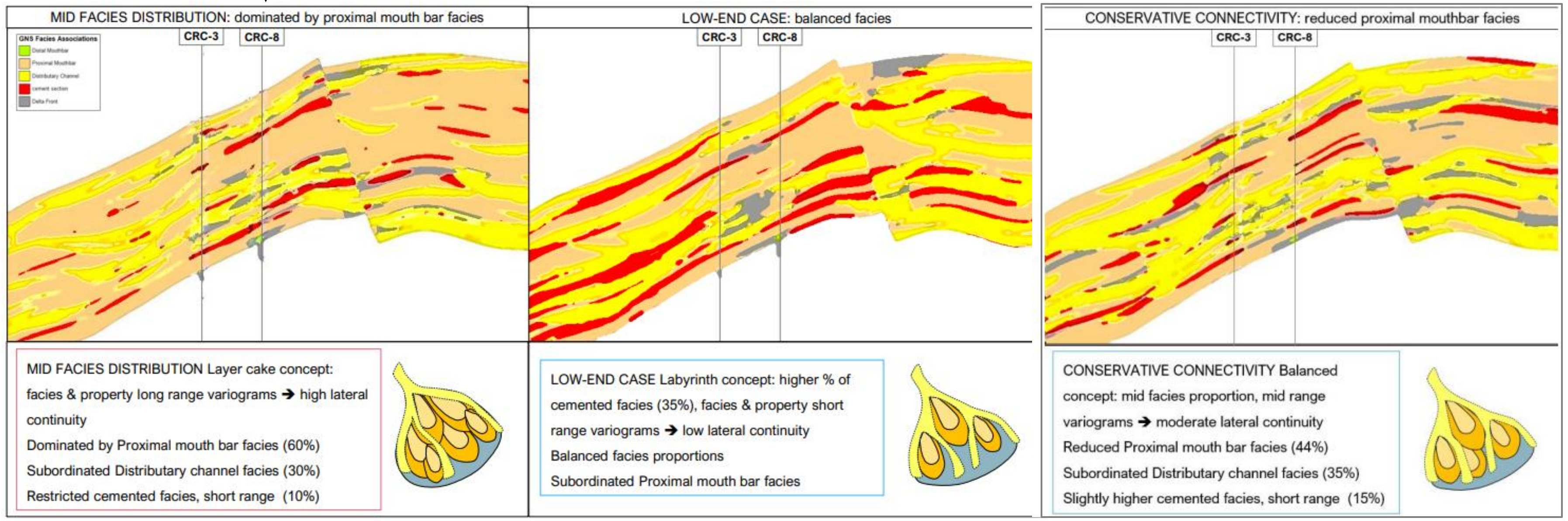
Heterogeneities important in understanding a tidal delta system need to be incorporated

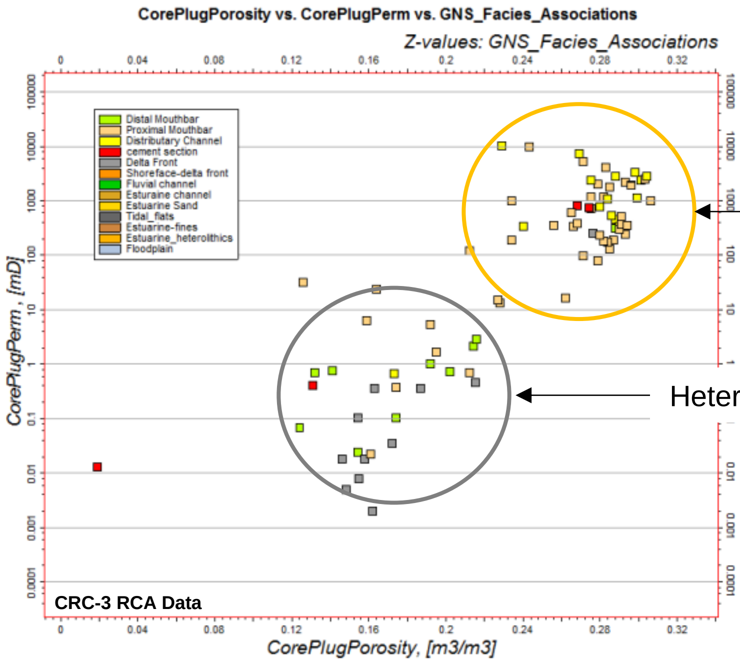


Static models do not look like tidal sand bars as there is limited muddy facies captured for heterogeneity

Cements are largely nodular so increasing their proportion/continuity here does not represent the geology observed in the core data, nor what is expected

"Muddy" facies being increased in this model are in the distributary channels – these facies in core are not mud-rich (as the RCA data demonstrates)





Sandy Facies (targeted sampling)

Heterolithic Facies (not included/under sampled)

RCA = Routine Core Analysis

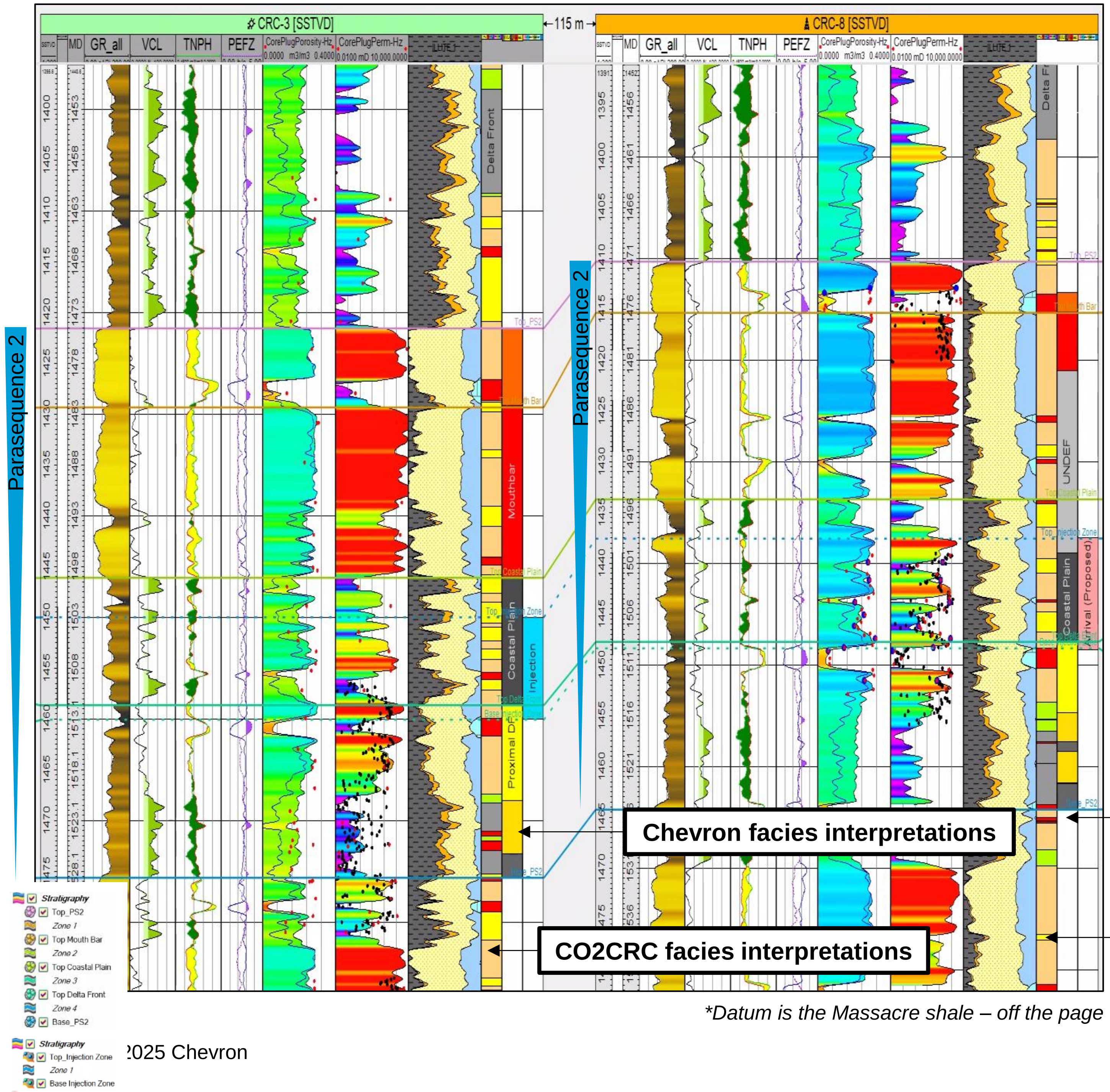
Facies initially identified in the injection well were interpreted as deposited in the proximal, sand-rich portions of a tidal delta, with little to no preservation of the mud-rich facies in either the proximal or distal areas

The core images, FMI, and petrophysics demonstrate much more mud in this system than has been captured in the static model to date

- Proximal Mouth Bar
- Distributary Channel
- Cemented Zone
- Delta Front
- Distal Mouth Bar

CRC-8 Parasequence 2

Chevron facies interpretations



NEW!!!

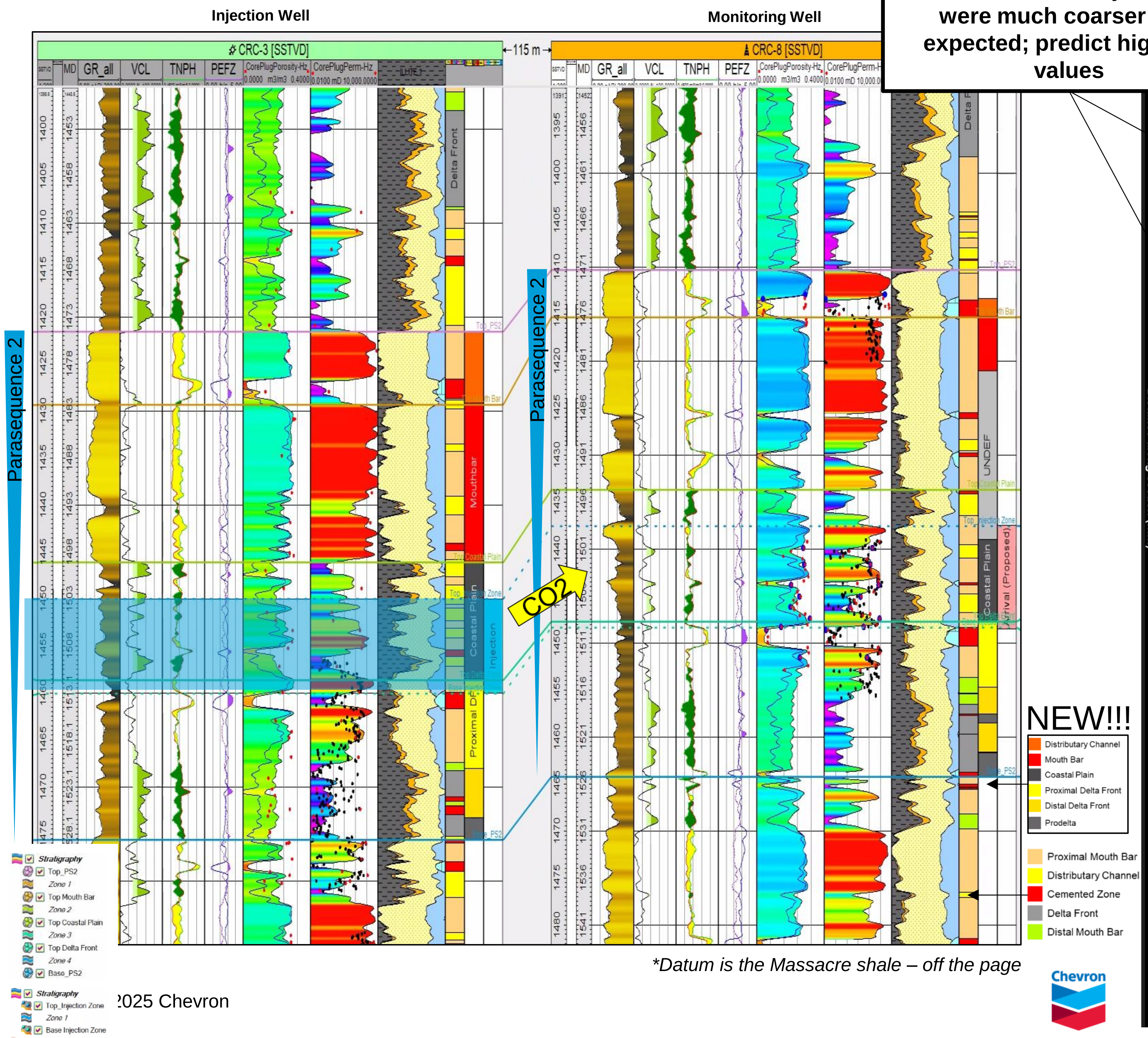
- Distributary Channel
- Mouth Bar
- Coastal Plain
- Proximal Delta Front
- Distal Delta Front
- Prodelta

- Proximal Mouth Bar
- Distributary Channel
- Cemented Zone
- Delta Front
- Distal Mouth Bar

*Datum is the Massacre shale – off the page

Injection Interval

CRC-3 injection well



*Datum is the Massacre shale – off the page

Reservoir facies injected into were much coarser than expected; predict higher k_h values

Coastal plain facies

Crevasse splay deltaic lobes with fine/coarse bay fill

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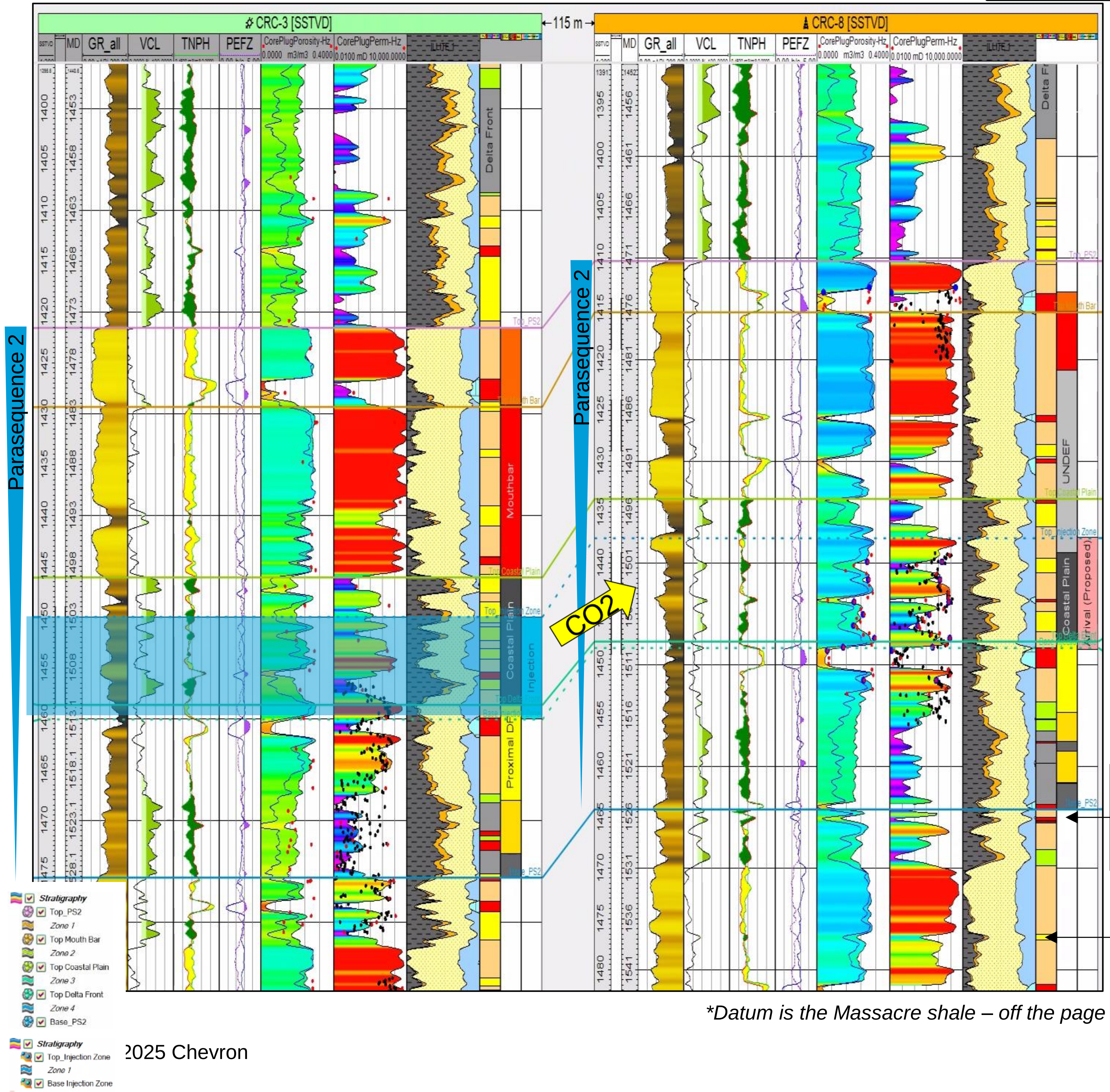
Injection Interval

CRC-3 injection well

Injection Well

Monitoring Well



NEW!!!

- Distributary Channel
- Mouth Bar
- Coastal Plain
- Proximal Delta Front
- Distal Delta Front
- Prodelta

- Proximal Mouth Bar
- Distributary Channel
- Cemented Zone
- Delta Front
- Distal Mouth Bar

*Datum is the Massacre shale – off the page

Injected into heterolithic baffle facies too

Coastal plain facies

Crevasse splay deltaic lobes with fine bay fill

Delta front facies

Proximal delta front

	WELL NAME	SAMPLE NUMBER	SAMPLE DEPTH (m)	CONFINING STRESS		
				PERMEABILITY		POROSITY (%)
				Kinf (md)	Kair (md)	
262	CRC-3	88	1492.64	2770	2810	28.8
263	CRC-3	87	1495.90	2010	2040	27.9
264	CRC-3	86V	1499.03	16.2	19.6	26.2
265	CRC-3	85	1499.10	730	747	27.5
266	CRC-3	84	1499.40	1110	1140	29.9
267	CRC-3	83	1501.00	0.706	0.831	13.2
268	CRC-3	82	1502.90	337	357	24.0
269	CRC-3	81	1505.00	0.748	0.904	14.1
270	CRC-3	80	1505.85	0.996	1.46	19.2
271	CRC-3	79	1506.92	247	262	29.3
272	CRC-3	78	1508.12	460	476	28.8
273	CRC-3	77	1508.80	345	353	26.6
274	CRC-3	76	1510.75	2.14	2.82	21.4
275	CRC-3	75	1513.60	191	198	23.4
276	CRC-3	74	1516.65	5.28	6.35	19.2

RCA Gross Interval kavg 206 mD

RCA Reservoir kmin = 1.46 mD

RCA Reservoir kmax = 476 mD

RCA Baffle kmin = 0.90 mD

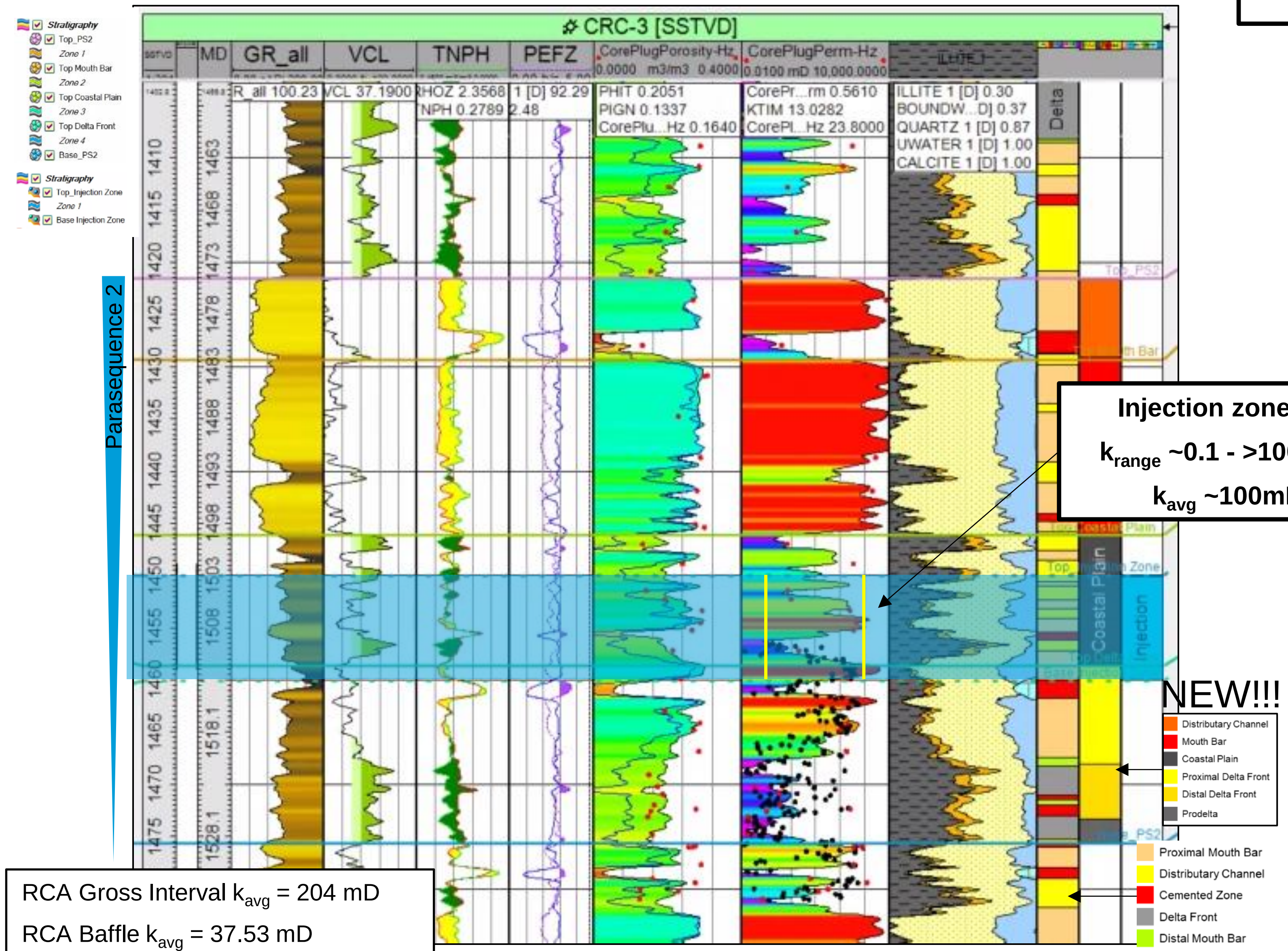
RCA Baffle kmax = 2.14 mD

RCA = Routine Core Analysis

Gas Injectivity

Capturing the ranges of geological uncertainty associated with the coastal plain

Injection Well



Injection zone k_{log}

k_{range} ~0.1 - >1000mD

k_{avg} ~100mD

RCA Gross Interval k_{avg} = 204 mD

RCA Baffle k_{avg} = 37.53 mD

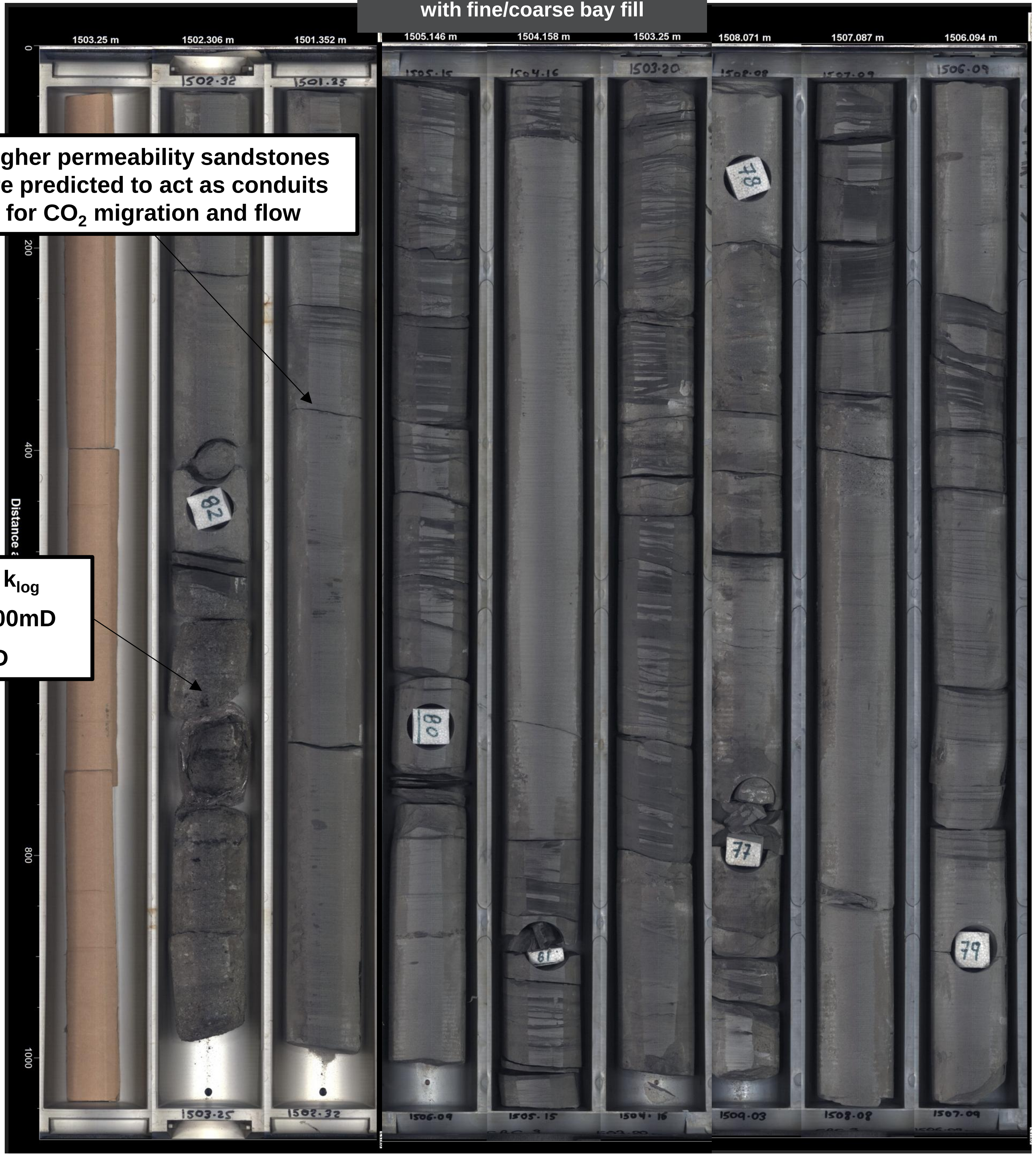
RCA Reservoir k_{avg} = 360 mD

RCA k_{avg} data is typically higher than k_{hlog} data

Coastal plain facies

Crevasse splay deltaic lobes with fine/coarse bay fill

Higher permeability sandstones are predicted to act as conduits for CO_2 migration and flow



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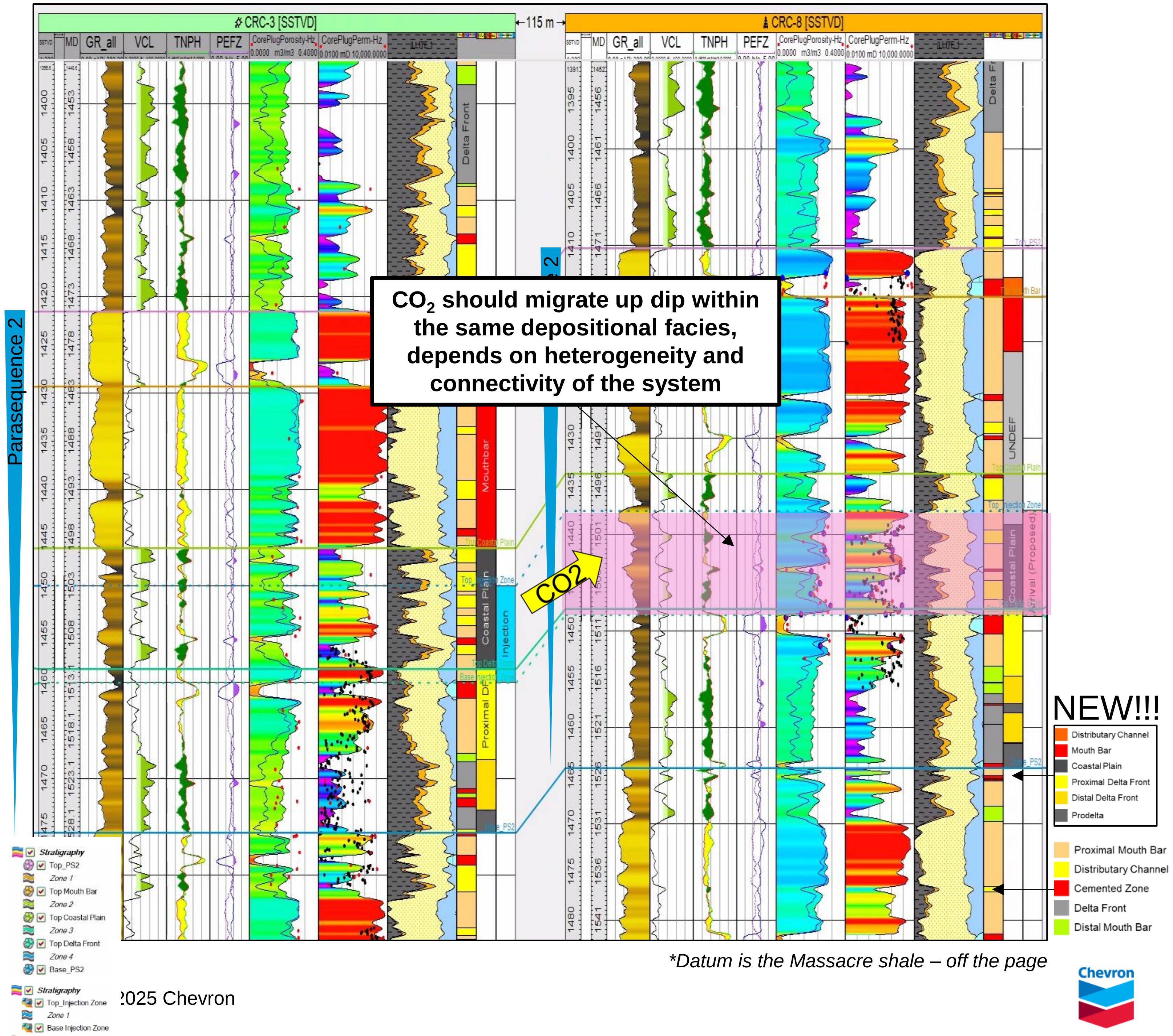
Predicted Stratigraphic Arrival Zone and Facies

CRC-8 monitoring well – reservoir facies



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	WELL NAME	SAMPLE NUMBER	SAMPLE DEPTH (m)	CONFINING STRESS		
				PERMEABILITY		POROSITY (%)
				Kinf (md)	Kair (md)	
340	CRC-8	6	1475.75	0.210	0.285	3.4
341	CRC-8	7	1476.30	523	527	29.1
342	CRC-8	8	1476.63	441	444	29.6
343	CRC-8	9	1476.92	564	571	29.0
344	CRC-8	10	1501.22	752	763	29.7
345	CRC-8	11	1501.90	193	204	27.9
346	CRC-8	12	1502.23	1.64	2.20	20.1
347	CRC-8	13	1502.77	0.457	0.554	15.5
348	CRC-8	14	1502.87	-	-	-
349	CRC-8	15	1503.08	63.2	70.7	27.0
350	CRC-8	16	1503.65	127	140	28.5
351	CRC-8	17	1504.20	136	149	28.6
352	CRC-8	18	1504.95	633	649	30.5
353	CRC-8	19	1505.40	654	672	27.8
354	CRC-8	20	1505.66	8.52	11.1	5.9
355	CRC-8	21	1505.84	684	688	20.5
356	CRC-8	22	1506.55	246	255	23.9
357	CRC-8	23	1507.07	18.4	21.6	25.9
358	CRC-8	24	1507.46	4.78	6.05	21.7
359	CRC-8	25	1507.80	6.66	8.48	23.7
360	CRC-8	26	1508.17	2.04	2.63	20.5
361	CRC-8	27	1508.43	2.85	3.71	22.0
362	CRC-8	28	1508.93	116	129	28.6
363	CRC-8	29	1509.08	25.3	29.7	25.4
364	CRC-8	30	1509.42	820	830	31.7
365	CRC-8	31	1510.05	459	473	29.9
366	CRC-8	32	1510.30	31.9	34.4	14.5

RCA Gross Interval kavg = 204 mD

RCA Reservoir kmin = 11.1 mD

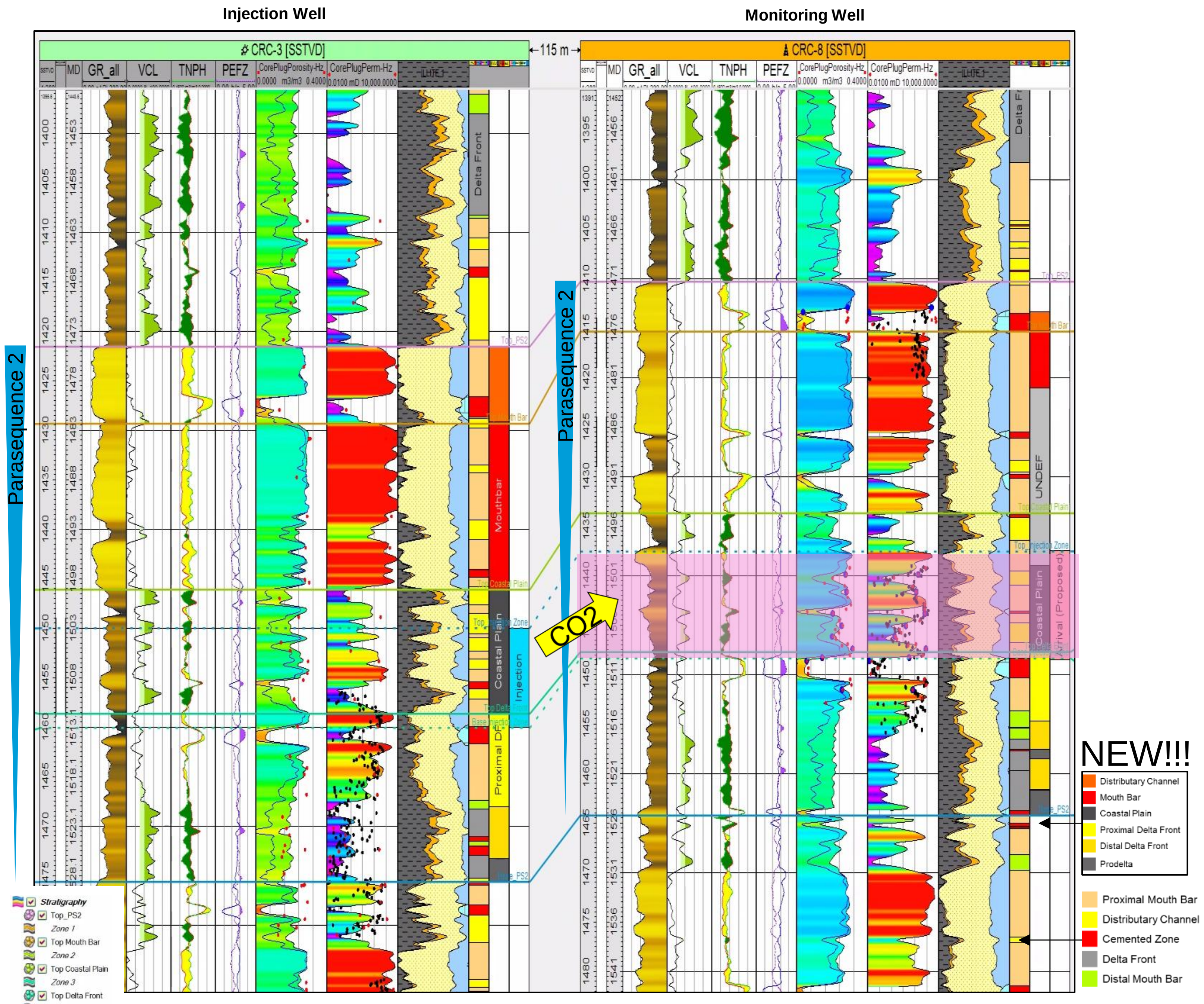
RCA Reservoir kmax = 830 mD

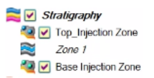
Predict lateral connection of sandstone reservoir facies between wells based on similarities in facies and log signatures

RCA = Routine Core Analysis

Predicted Stratigraphic Arrival Zone and Facies

CRC-8 monitoring well – baffle facies





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	A	B	C	D	E	F
1–3	WELL NAME	SAMPLE NUMBER	SAMPLE DEPTH (m)	CONFINING STRESS		
				PERMEABILITY		POROSITY (%)
				Kinf (md)	Kair (md)	
340	CRC-8	6	1475.75	0.210	0.285	3.4
341	CRC-8	7	1476.30	523	527	29.1
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343	CRC-8	9	1476.92	564	571	29.0
344	CRC-8	10	1501.22	752	763	29.7
345	CRC-8	11	1501.90	193	204	27.9
346	CRC-8	12	1502.23	1.64	2.20	20.1
347	CRC-8	13	1502.77	0.457	0.554	15.5
348	CRC-8	14	1502.87	-	-	-
349	CRC-8	15	1503.08	63.2	70.7	27.0
350	CRC-8	16	1503.65	127	140	28.5
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357	CRC-8	23	1507.07	18.4	21.6	25.9
358	CRC-8	24	1507.46	4.78	6.05	21.7
359	CRC-8	25	1507.80	6.66	8.48	23.7
360	CRC-8	26	1508.17	2.04	2.63	20.5
361	CRC-8	27	1508.43	2.85	3.71	22.0
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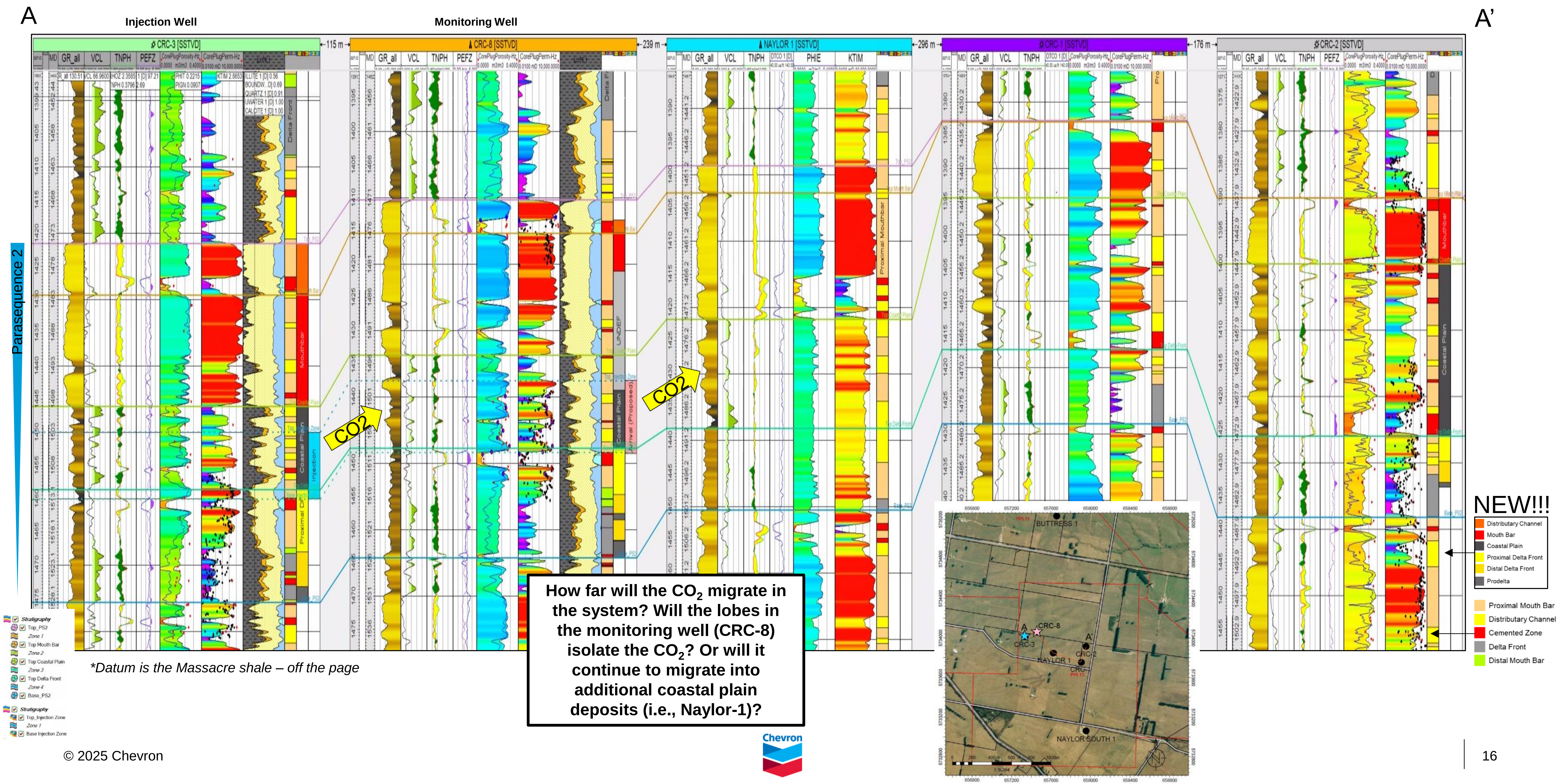
363	CRC-8	29	1509.08	25.3	29.7	25.4
364	CRC-8	30	1509.42	820	830	31.7
365	CRC-8	31	1510.05	459	473	29.9
366	CRC-8	32	1510.30	31.9	34.4	14.5

RCA Gross Interval kavg = 204 mD
RCA Baffle kmin = 0.55 mD
RCA Baffle kmax = 255 mD

Tortuous path for the CO_2 to travel through these complex, baffle facies; baffle/potential seal character depends on permeability, continuity, thickness, and degree of heterogeneity

RCA = Routine Core Analysis

Regional Stratigraphic Cross-Section



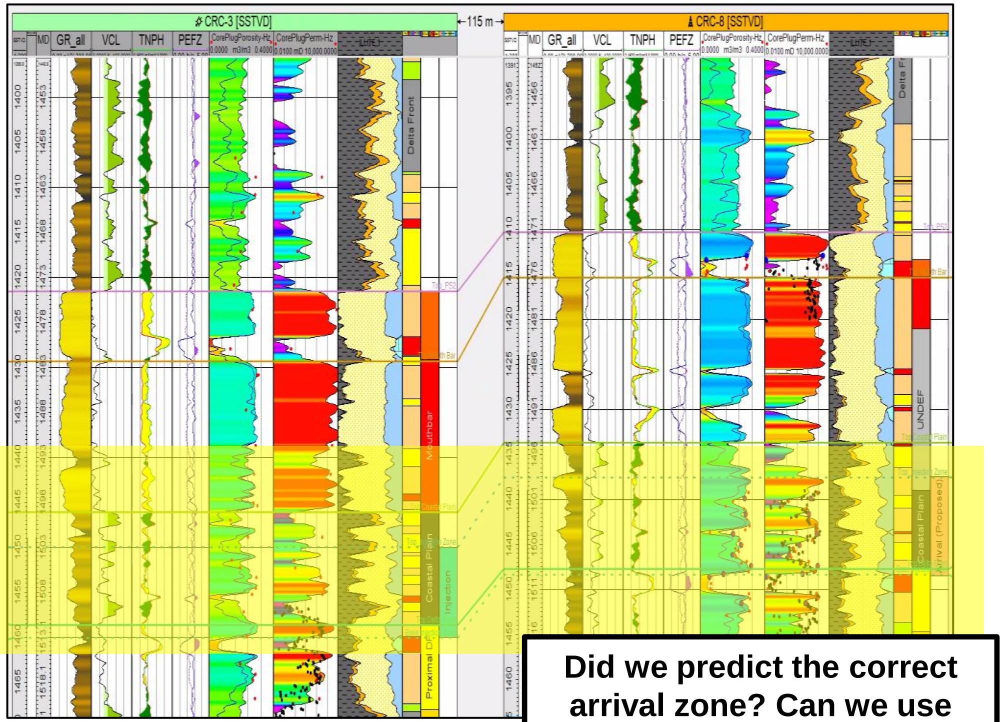
**Datum is the Massacre shale – off the page*

How far will the CO_2 migrate in the system? Will the lobes in the monitoring well (CRC-8) isolate the CO_2? Or will it continue to migrate into additional coastal plain deposits (i.e., Naylor-1)?

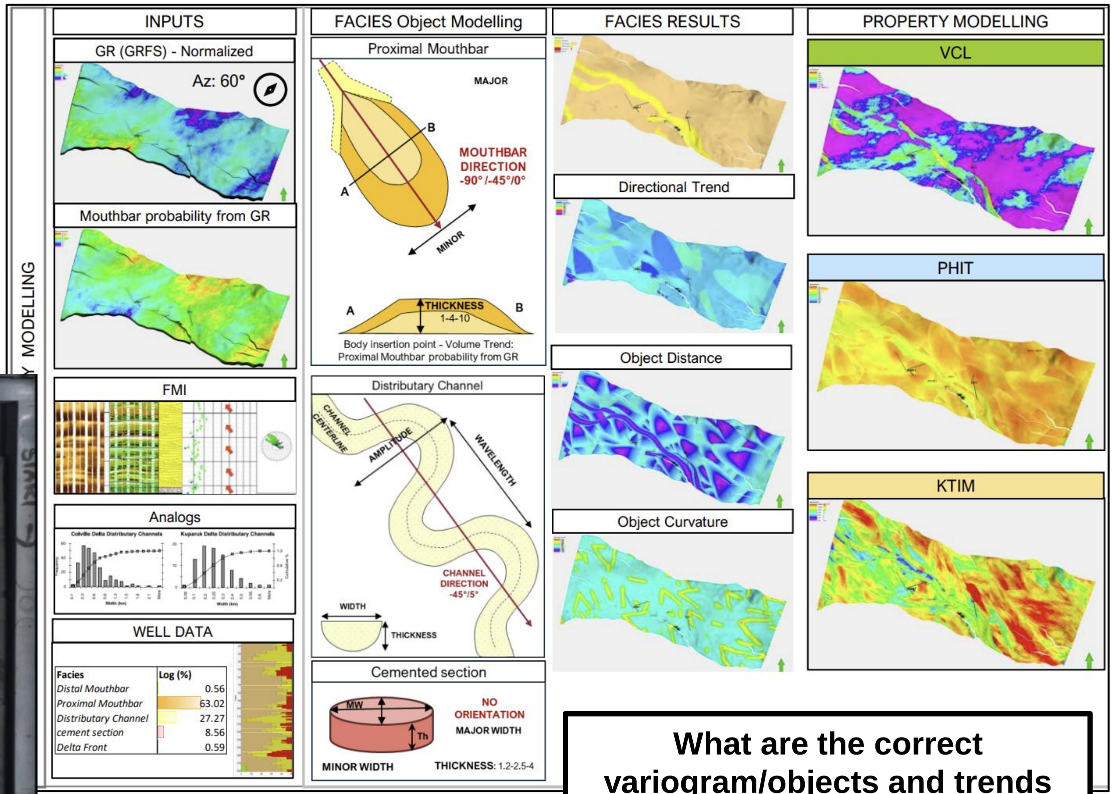
Ongoing Work

What to consider next?

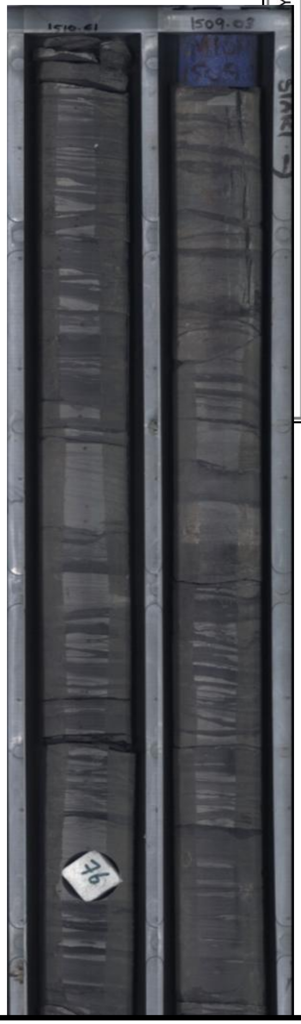
Did we get all the information we can from the data we collected? What else can we extract from what we have?

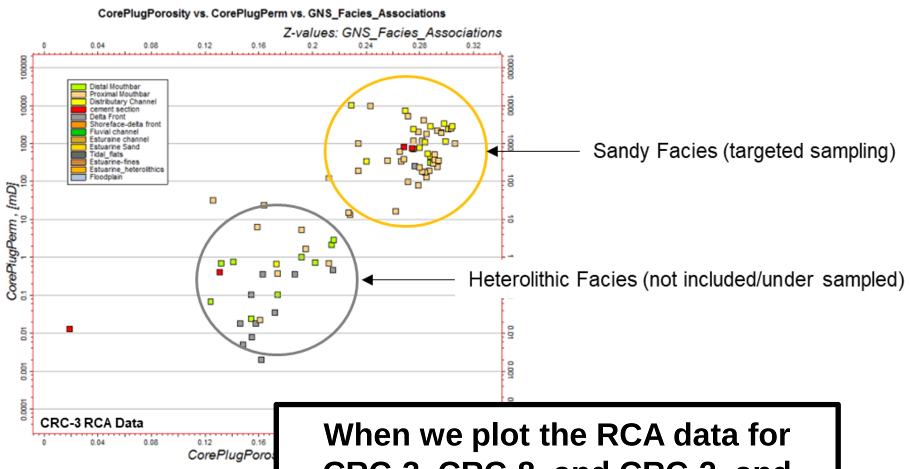


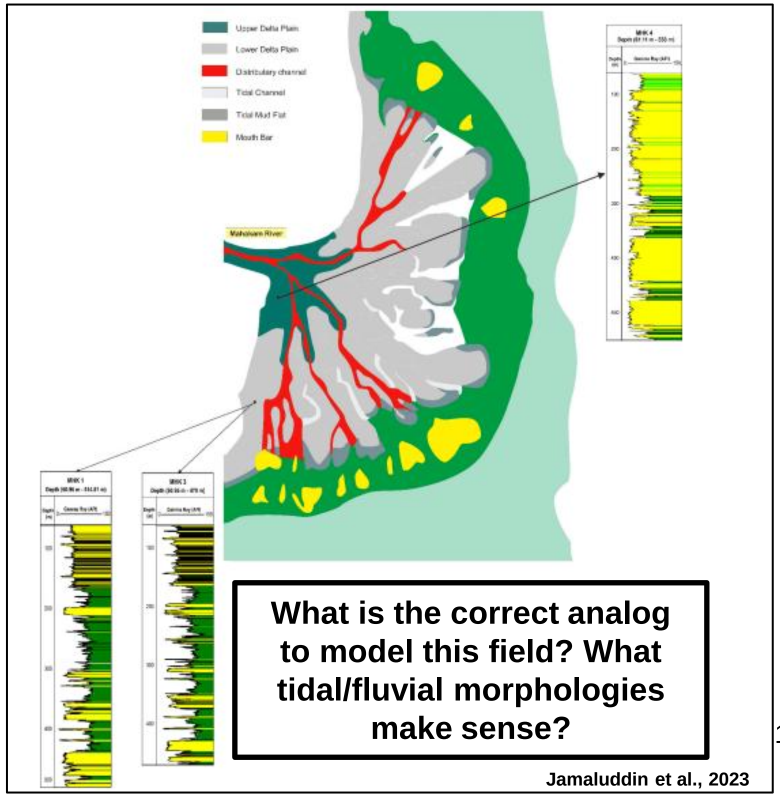
Did we predict the correct arrival zone? Can we use CO_2 plume migration to predict geology?



What are the correct variogram/objects and trends to use in our reservoir models?







What are the correct facies to sample for RCA? Did we sample enough to inform our reservoir models?

When we plot the RCA data for CRC-3, CRC-8, and CRC-2, and color by the new facies, what do the distributions look like?

Complex baffles, can they also be composite seals in some instances? What makes a good seal in tidal deltaic reservoirs? We need to think outside of the box.

What is the correct analog to model this field? What tidal/fluvial morphologies make sense?

Jamaluddin et al., 2023

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- Why does it matter?

Why does it matter?

Small-scale changes within the facies of the tidal depositional system (i.e., grain-size and clay content), can have major impacts on permeability and porosity. Understanding heterogeneity, specifically, its spatial arrangement and stacking patterns in the subsurface, along with approximate facies/geobody geometries, effects multiple areas in a carbon capture and sequestration project.

The distribution and heterogeneity of depositional facies within the subsurface controls:

- Kv/Kh
- Reservoir, baffle, barrier connectivity
- Injection rates
- Flow migration and plume extent (vertical/lateral)
- Pressure build up
- CO_2 break through time
- Storage capacity
- Capillary trapping
- Mineral trapping
- Baffle and seal capacity
- Long-term containment and conformance

The questions we are trying to answer with this work are, what level of resolution in our reservoir models best captures the impact of geological heterogeneity? And what can we predict from these models? To test this, we need detailed geological characterization, accurate geological models, and high-resolution reservoir modelling.

CO2CRC acknowledges and appreciates the strong relationships it has with industry, community, government, research organisations, and agencies in Australia and around the world.

QUESTIONS?

the human energy company®

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