LESSONS LEARNED FROM FAILURES

BYPASSED PAYS: OPPORTUNITIES FOR LARGE RESERVE ADDITIONS

Robert M. Sneider

Larry D. Meckel

David G. Smith

- WEST AFRICA GIANT FIELD
  - ALMOST MISSED
- ELMWORTH SUPERGIANT GAS FIELD ALBERTA, CANADA
  - 61 DRY HOLES DRILLED PRIOR TO DISCOVERY

SOME COMMON REASONS FOR FAILURES

- Poor Integration of Geoscience and Engineering Data
- Incorrect Petrophysical Models
  - Effect of Conductive Minerals (Clays, Pyrite)
  - Incorrect Archie “m” and “n”
- Understanding Connate Water Saturation (S_w) vs Irreducible Water Saturation (S_{wirr}) Plus S_w
- Recognize Damaged Zones vs Low Perm. Zones

RMS045836A

SOME COMMON REASONS FOR FAILURES

- Recognize Pressure Seals' Role in Trapping
- Recognize Lower Limits of Pay Using ϕ and S_w Cutoffs Considering Stimulation Procedures
- Recognize Opportunities, Technical Improvements and Economic Trends from Similar Basins and Geology that can Apply to the Play / Prospect
- No Sales Outlet (e.g. Pipelines)

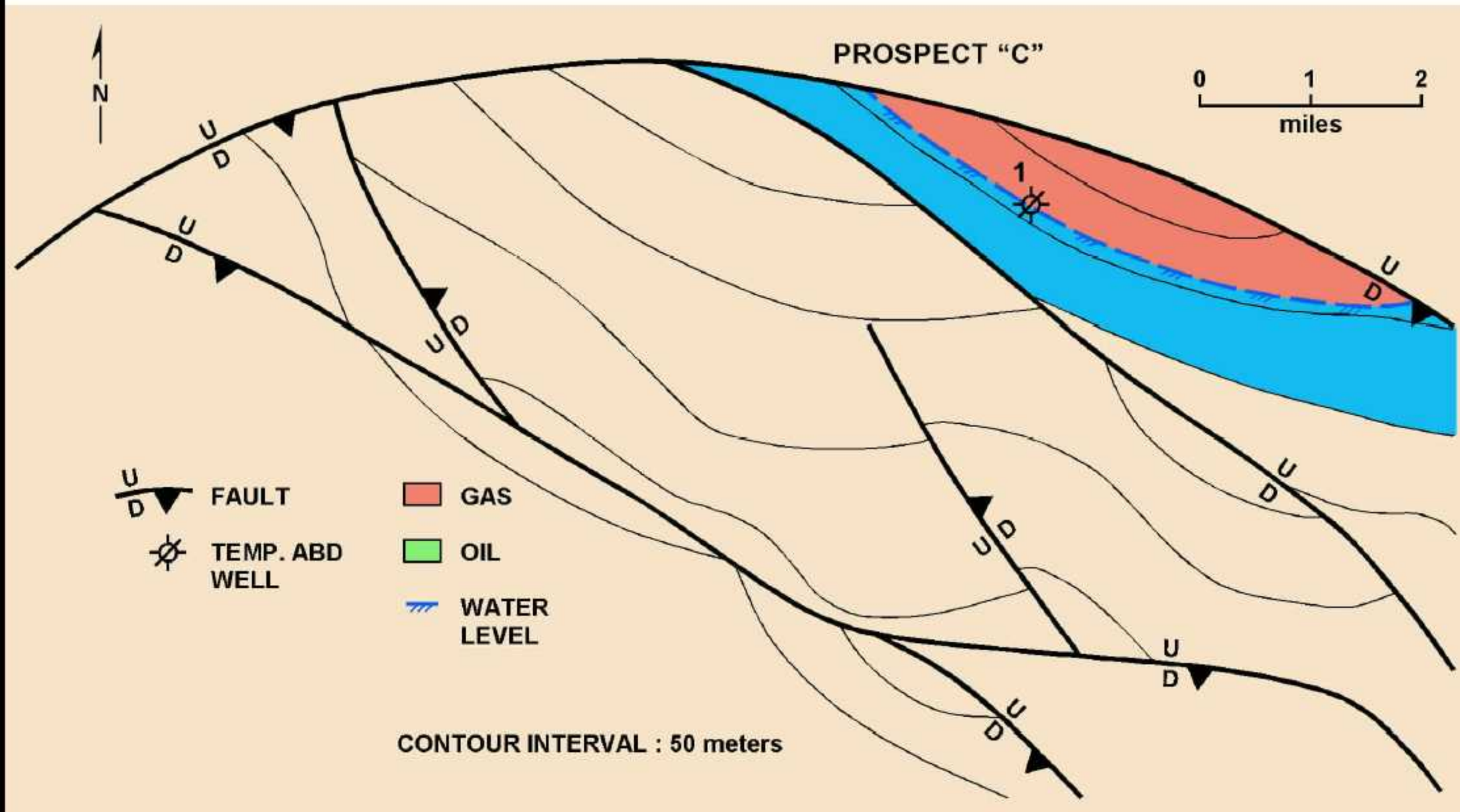
PROSPECT "C"

OFFSHORE, WEST AFRICA

ALMOST MISSED BILLION BARREL OIL AND CONDENSATE FIELD

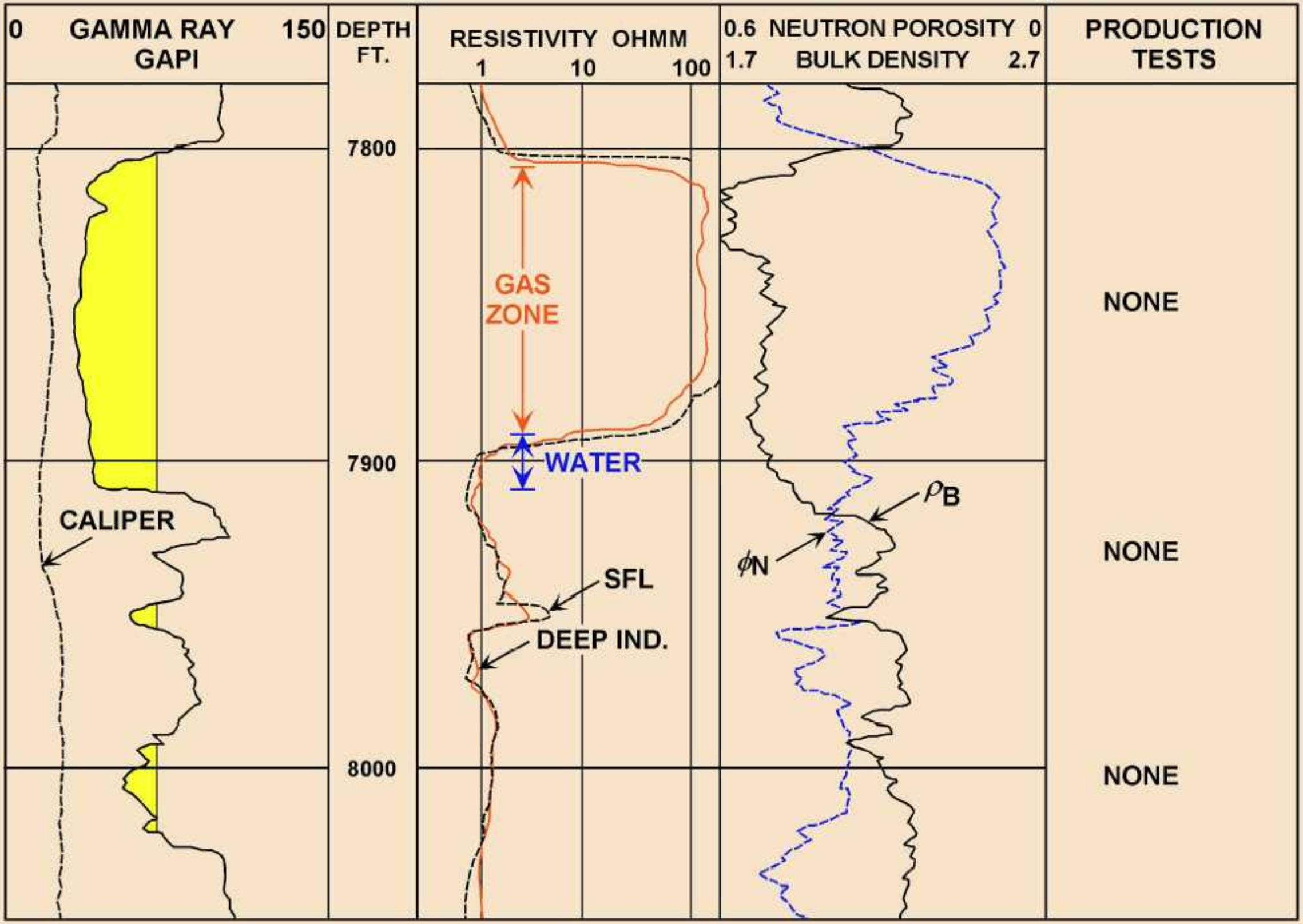
RMS045833

STRUCTURE MAP ON "M" SAND, PROSPECT "C", OFFSHORE W. AFRICA (BASED ON 3D SEISMIC AND 1 APPRAISAL WELL)



RMS045842

NO.1, "M" SAND, PROSPECT "C", OFFSHORE W. AFRICA



RMS045844

EVALUATION OF "M" SAND
WELL 1, PROSPECT "C"

28.3 m Gas Over Water

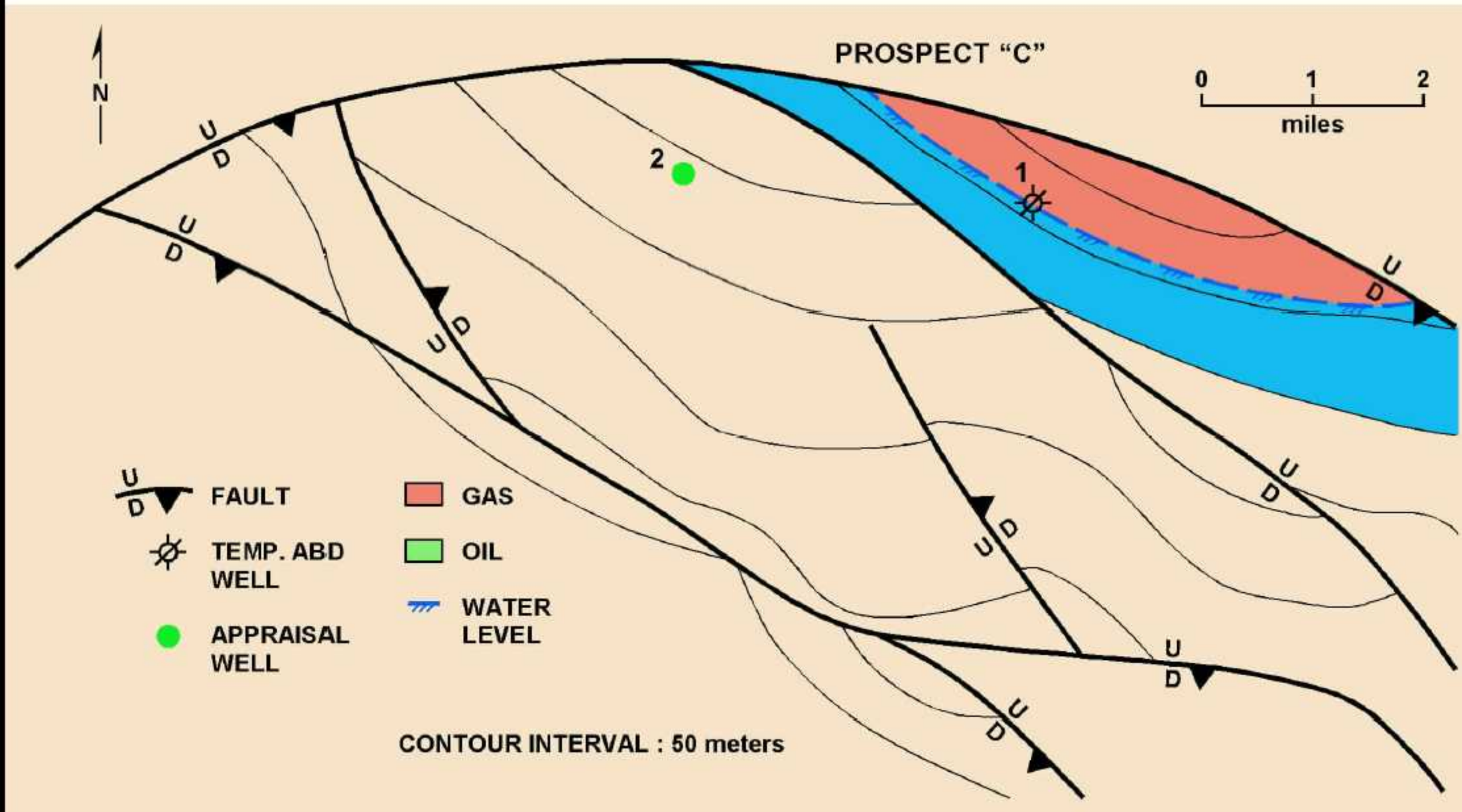
Porosity: 27 – 34%

Water Sat.: 64 – 81%

Tests:

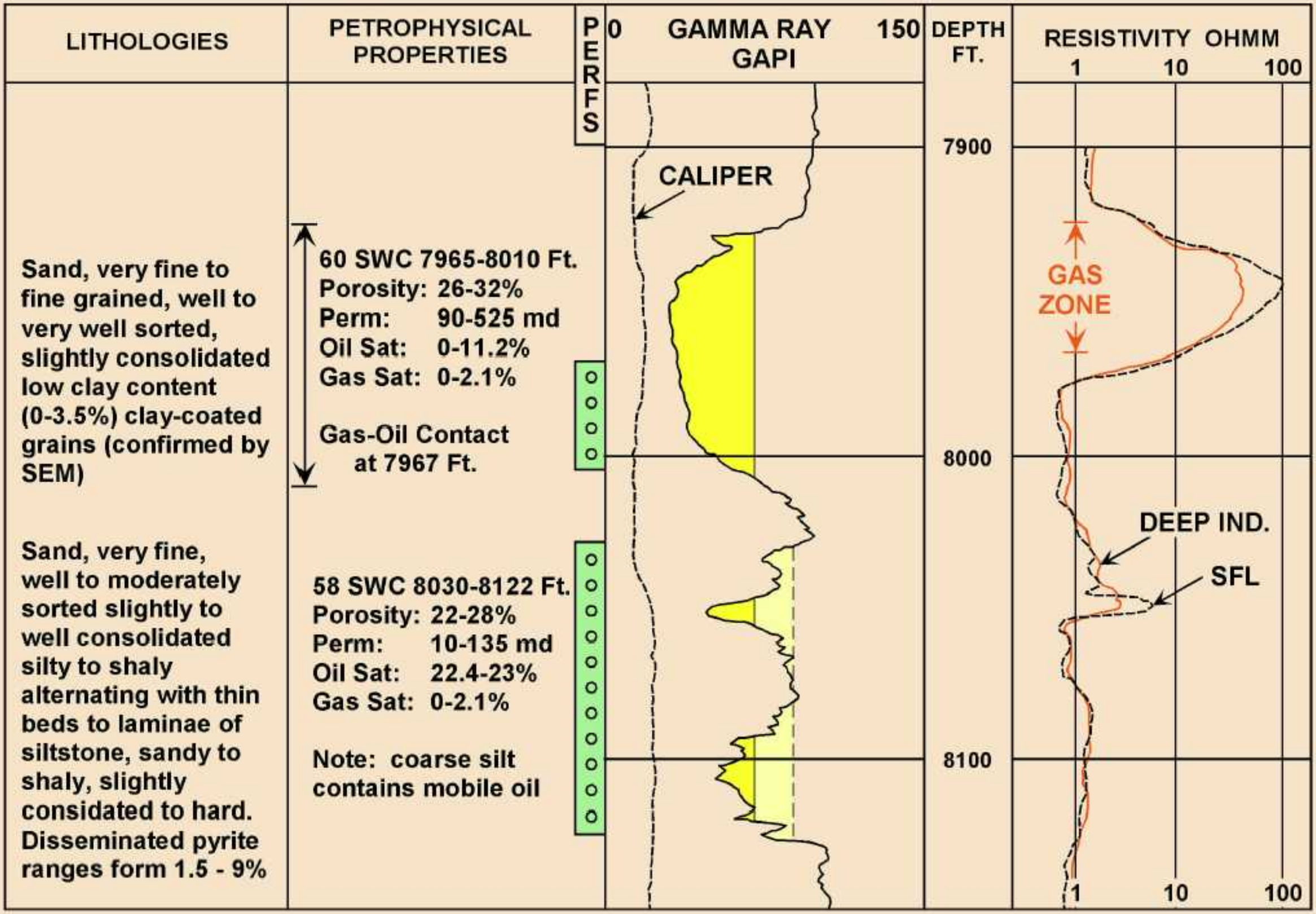
- None
- No Other Zones of Interest
- Temp. Abandoned;
- Not Economic

STRUCTURE MAP ON "M" SAND, PROSPECT "C", OFFSHORE W. AFRICA (BASED ON 3D SEISMIC AND 2 APPRAISAL WELLS)



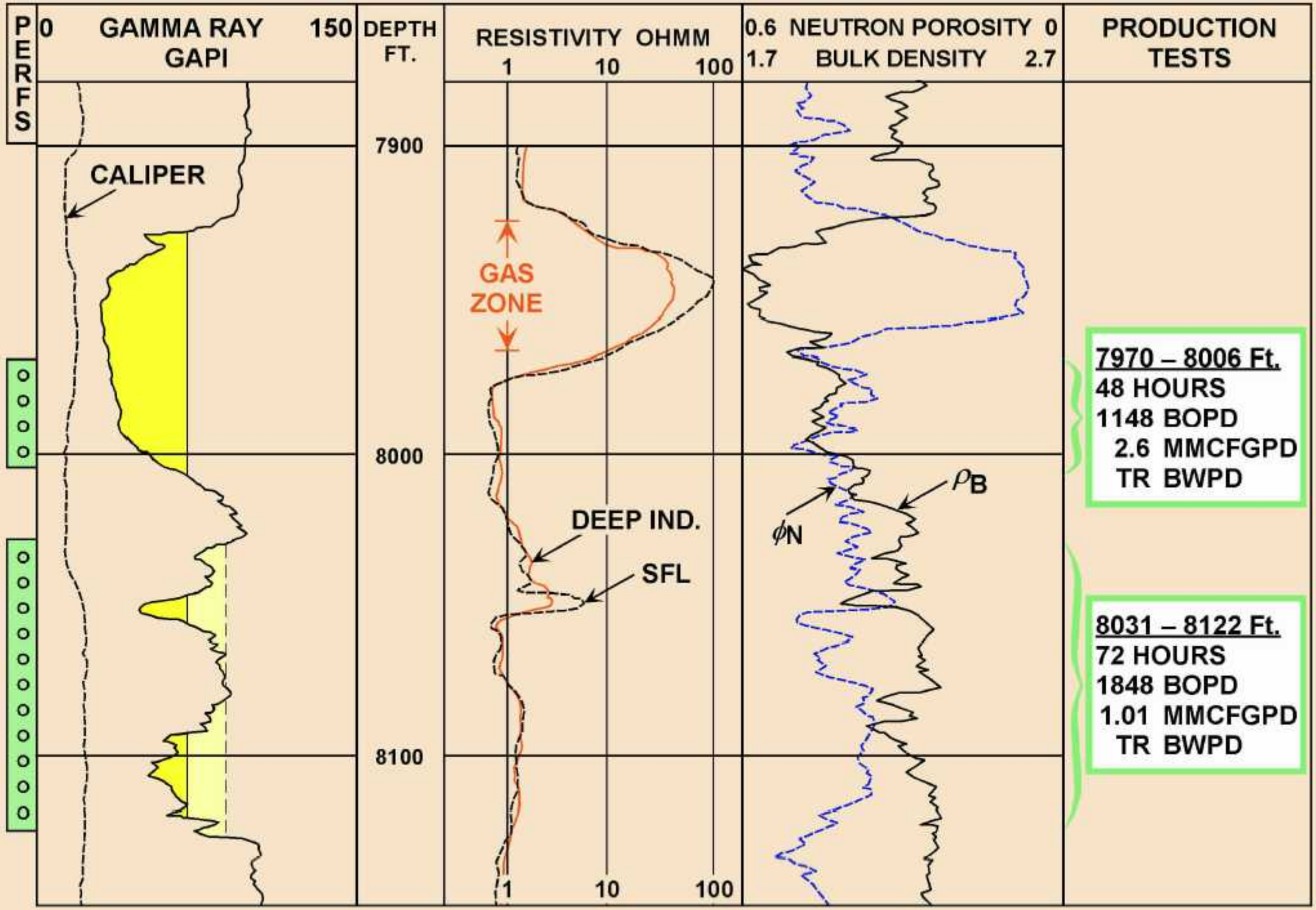
RMS045853

NO.2, "M" SAND, PROSPECT "C", OFFSHORE W. AFRICA



RMS025421

NO.2, "M" SAND, PROSPECT "C", OFFSHORE W. AFRICA



RMS025420

EVALUATION OF "M" SAND WELL 2, PROSPECT "C"

17.2 m Gas + Condensate

6.4 m Oil to Sand Base

0.0 m Water

ϕ and S_w as in Well 1

Tests:

- High Flow Rates
- 6 Other LRLC Zones

Est. Recoverable Reserves:

1.03 Billion Barrels of Oil and Condensate

EVALUATION OF WELL NO. 2

"M" LRLC SAND, PROSPECT "C", OFFSHORE W. AFRICA

	FIRST	SECOND
POROSITY (%)	26 – 32	26 – 32
MICROPOROSITY (%)	ND	5 – 6
WATER SAT. (S_w, %)	63 – 75	63 – 74
IRREDUCIBLE WATER SATURATION ($S_{w_{irr}}$, %)	ND	17 – 19
TESTS	NONE WELL TAed	HIGH FLOW OF HYDROCARBONS

RMS045839

ARCHIE PARAMETERS USED TO CALCULATE HYDROCARBON SATURATION

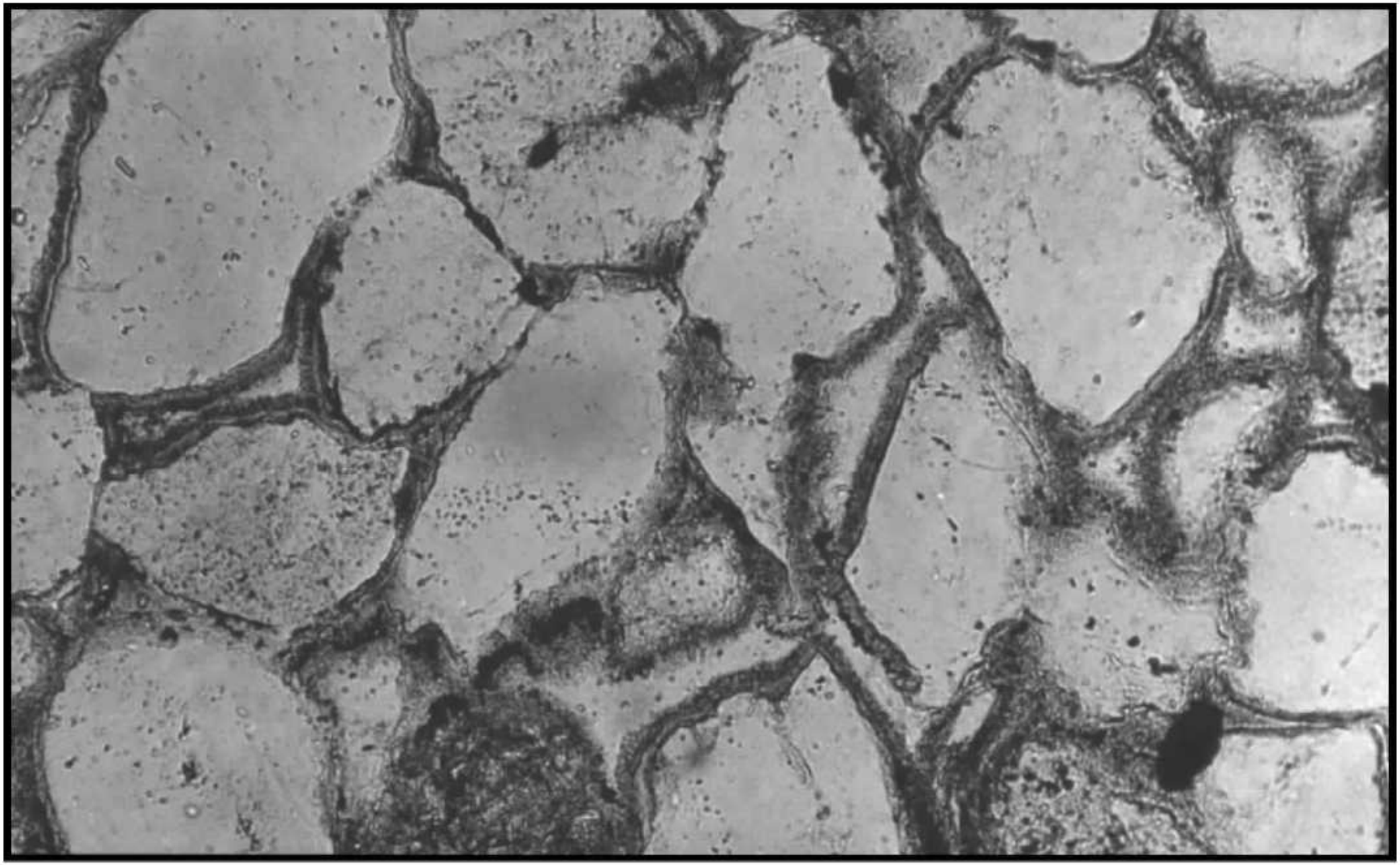
"M" SAND, PROSPECT "C", OFFSHORE W. AFRICA

	WELL 1 (INITIAL)	WELL 1 (RMS)*	WELL 2 (RMS)*
m	1.9	1.50	1.50 - 1.55
n	2.0	1.60	1.55 - 1.65
a	1	1	1

*From "Rock Catalog"

RMS045854

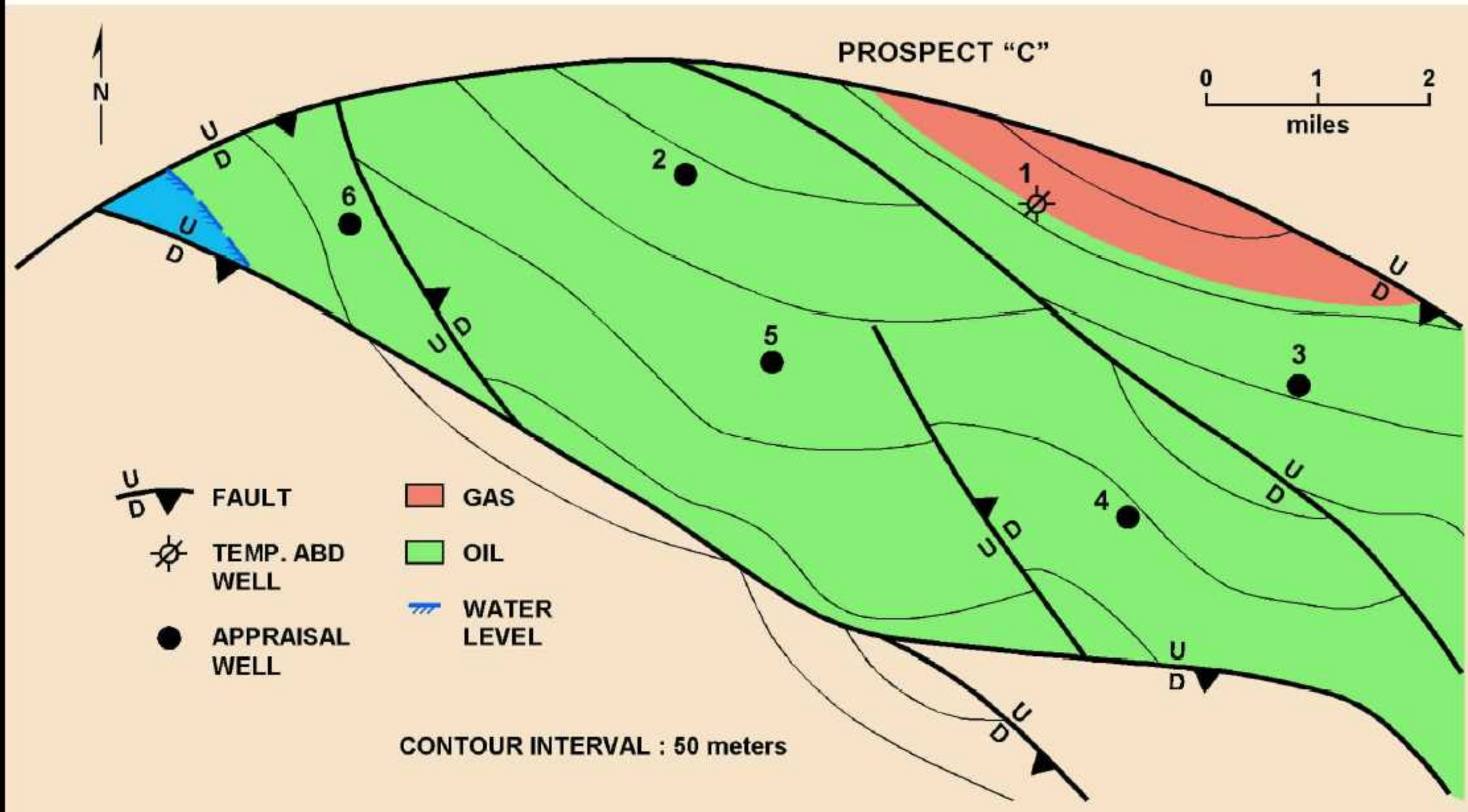
CLAY COATED SAND



0 0.2
mm

RMS923513

STRUCTURE MAP ON "M" SAND, PROSPECT "C", OFFSHORE W. AFRICA (BASED ON 3D SEISMIC AND 6 APPRAISAL WELLS)



RMS045843

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Est. Recoverable Reserves:

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RMS045840/5841

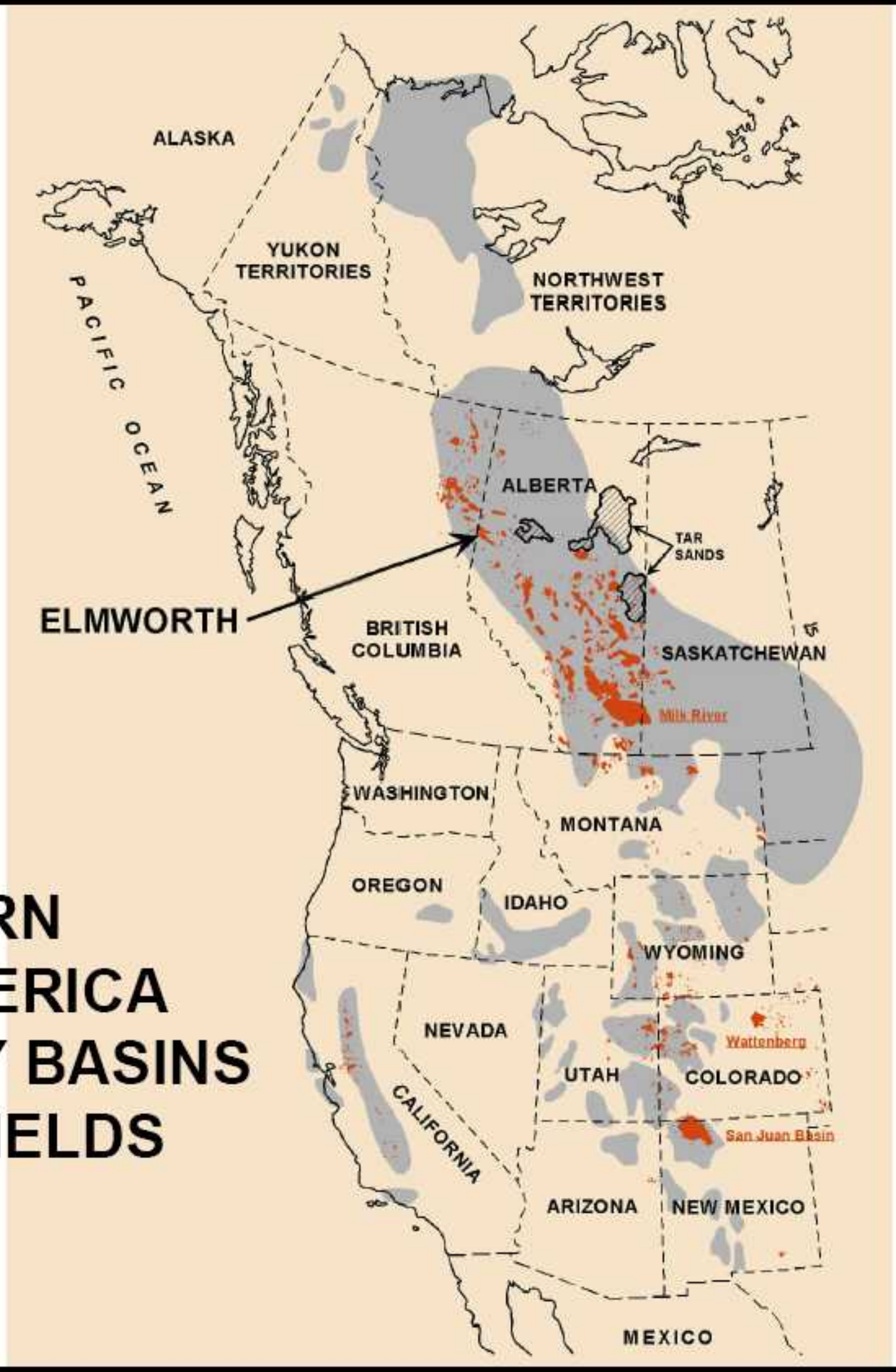
ELMWORTH FIELD

ALBERTA – B.C. DEEP BASIN

ORIGINALLY MISSED SUPERGIANT GAS FIELD

RMS045834

WESTERN NORTH AMERICA SEDIMENTARY BASINS AND GAS FIELDS



RMS045793

After Masters, 1979

ELMWORTH FIELD

- Supergiant Field in Alberta - B.C. Basin Syncline
- A Large Stratigraphic Trap with a Gas-Saturated Section over 720 Ft. Thick, over 65 Miles Long and 30 Miles Wide
- Over 2000 Producing Wells Develop 10 Major Reservoir Units Containing Several 10s of TCF Gas
- Reservoirs are Delta Front and Channels, Coastal Barrier and Marine Bars, and Alluvial Fans and Channels

ELMWORTH FIELD

- Sandstones have Porosities 7-11%; Perms 0.01 to 10 md. Conglomerates have Porosities 3-8%; Perms 0.1 to 80 md.; Some Perms Greater than 1Darcy
- Reservoir Units are Gas Saturated, Lower Pressure, and Tighter than Their Updip More Porous, Water-Bearing Equivalent Units
- Prior to Discovery in 1976, 61 Dry or Uneconomic Wells were Drilled Into or Through Lower Cretaceous Clastics that are Now Productive

ELMWORTH FIELD HIGHLIGHTS

- Canadian Hunter Expl. Ltd. Formed in 1973; Sneider - Meckel Formed in 1974.
- Early Discovery History
  - Sept. 1975, Reentry to the Cadotte FM: Uneconomic Flow
  - Nov. 1975, Reentry and Frac at Town: 2 MMcfgpd
  - Jan. 1976, Drilled into Porous Fahler Conglomerate: 26 MMcfgpd

    Log Analysis showed Gas in Every Sand from 2,500 to TD at 10,000 feet.
- From 1976 to 1980, Reentries and New Wells Demonstrated a Gas Saturated Area 100 Miles by 50 Miles in Alberta: 17 Cretaceous-Age Reservoirs in the Basin Center Rimmed by Updip Water. Trend Extends into British Columbia.

ELMWORTH FIELD HIGHLIGHTS

- 5,000 Square Mile Alberta Deep Basin Contains Low Perm. Reservoirs with Local High Perm Shoreface/Beach Conglomerate Zones. A Huge Stratigraphic Trap with Tens of TCF of Reserves and Gas-In-Place Resource.

- Wells Flowed from 1 to 30 Million Cubic Feet of Gas Per Day: Frac Stimulation Needed on Most Zones for Economic Production.

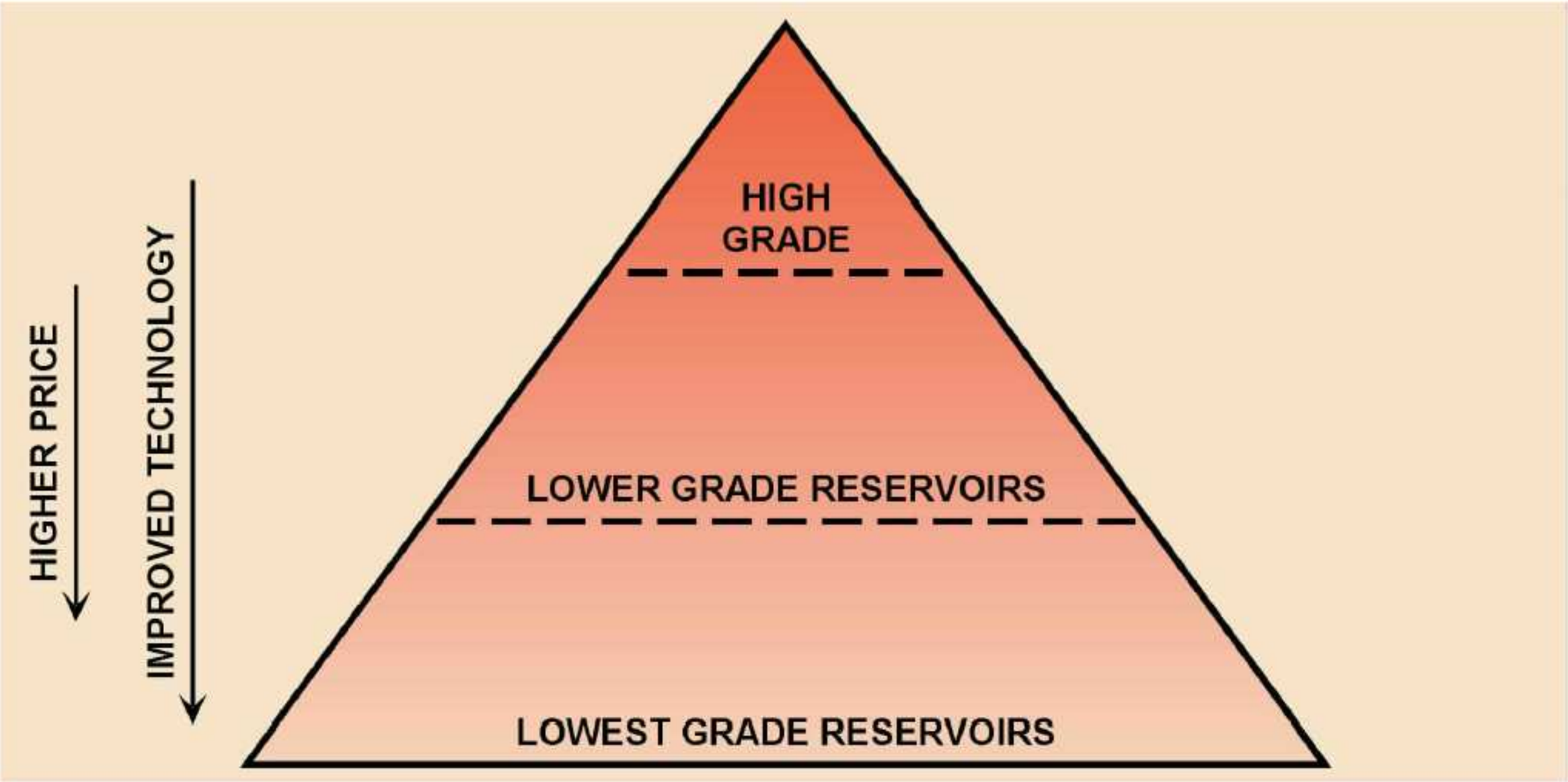
- Burlington Resources Purchased Canadian Hunter in December 2001.

EXPLORATION PLAN AND STRATEGY

- Explore Mainly for Gas Assuming Higher Future Gas Prices and Development of Better Well Completion and Stimulation Technology
- Use a Mining Principle: Low Grade Ore Deposits have Far Greater Total Reserves than High Grade Deposits (the Resource Triangle)
- Reexamine Well Logs of Uneconomic Wells and Dry Holes for Hydrocarbon Shows and Better Rock Types in Areas Containing Many Wells (Regional Scans)
- Integrate Geological, Petrophysical, Reservoir Engineering, and Completion/Stimulation Concepts and Technology to Understand Why a Well was Interpreted to be Dry or Uneconomic

J.K. GRAY'S RESOURCE TRIANGLE

(1977)



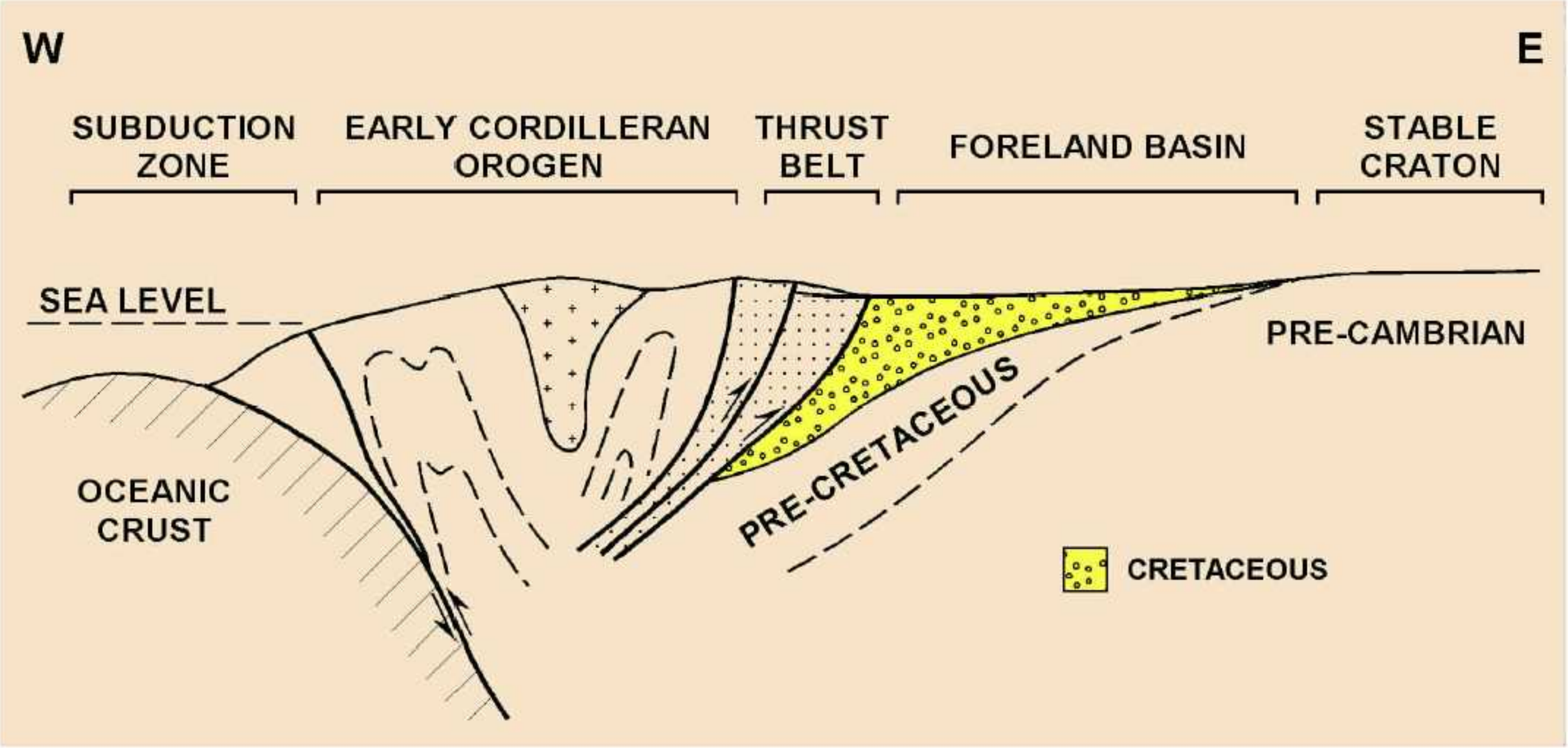
RMS045800

After J. K. Gray, 1977

GEOLOGY:

Structure and Stratigraphy

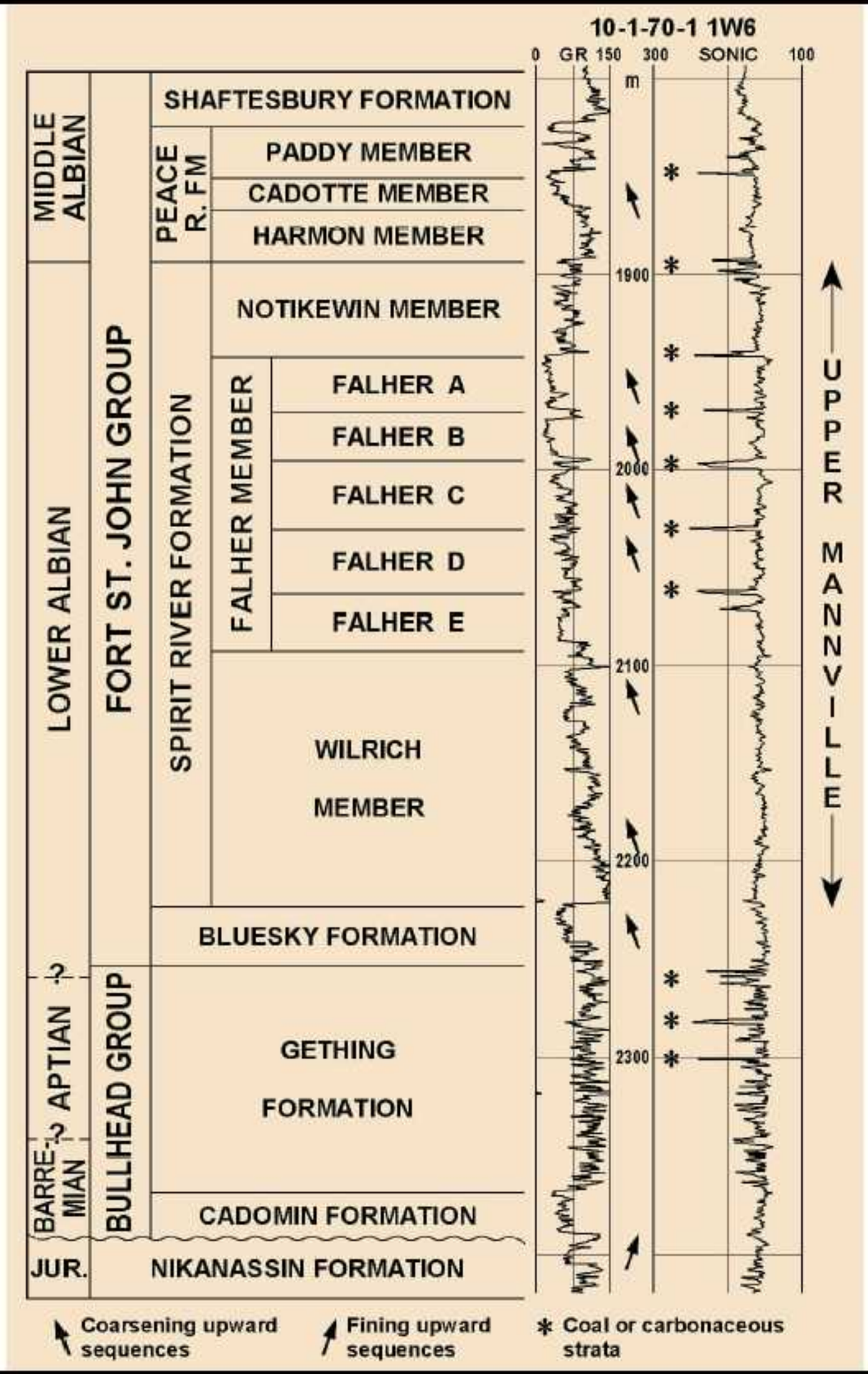
SCHEMATIC CROSS SECTION, ILLUSTRATING THE RELATIONSHIP OF THE UPLIFTED EARLY CORDILLERA TO THE FORELAND BASIN DURING THE CRETACEOUS



RMS045818

After Weimer, 1984; Eisbacher et al, 1974

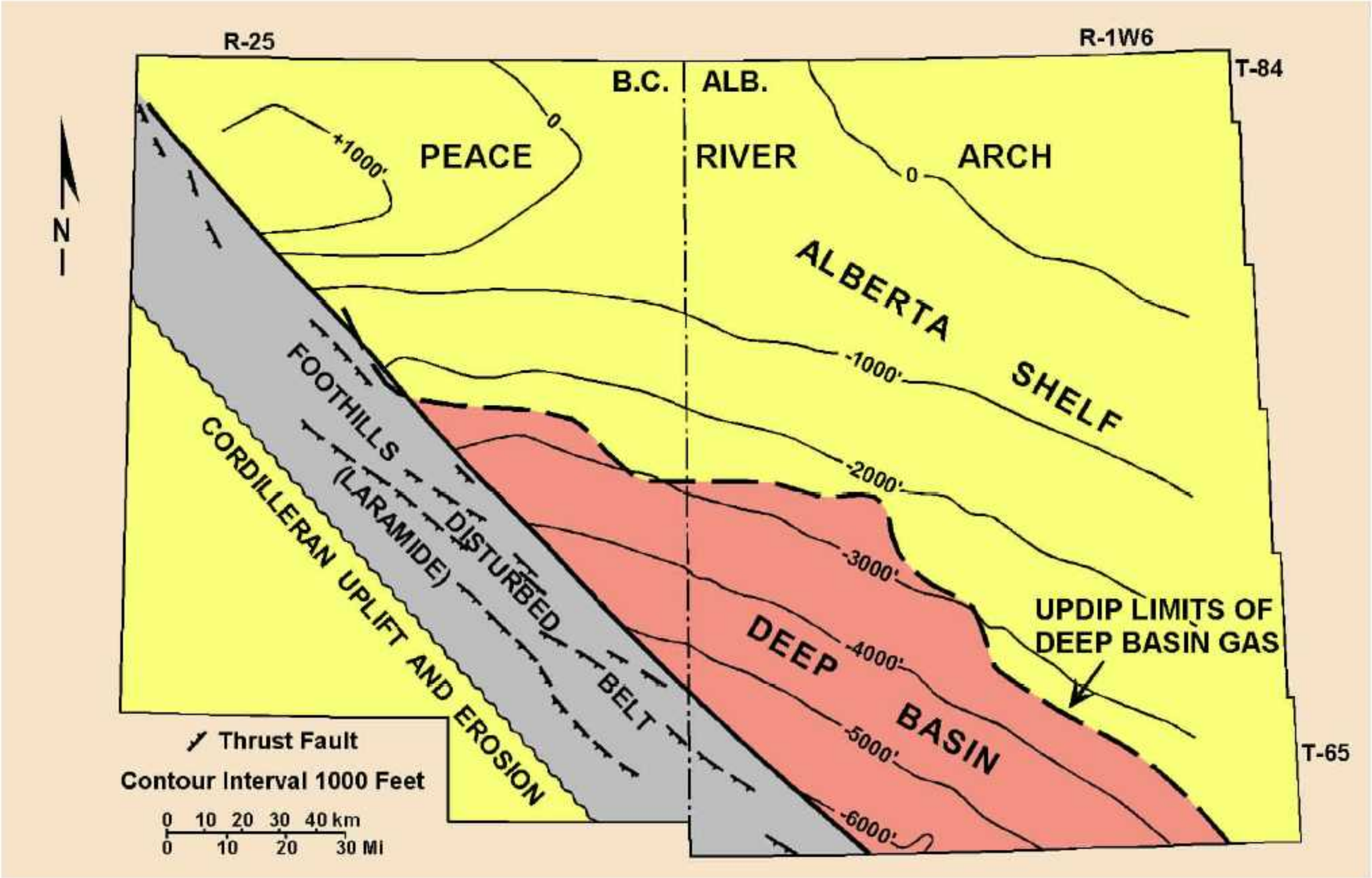
TYPE LOG
ELMWORTH FIELD
ALBERTA



RMS045817

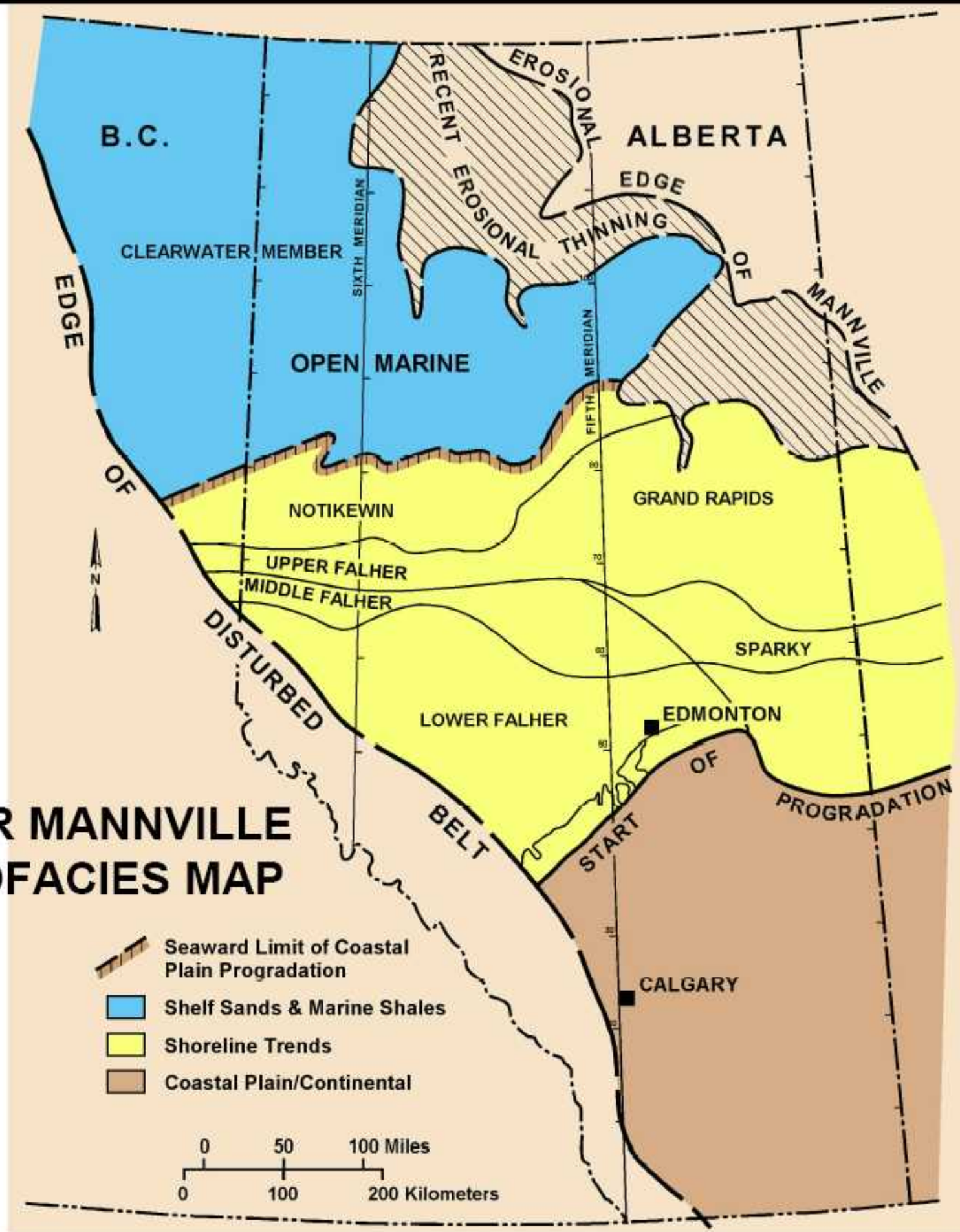
After Smith, Zorn, Sneider, 1983

ELMWORTH DEEP BASIN ON NOTIKEWIN STRUCTURE



RMS995266

After Smith, Zorn, Sneider, 1984

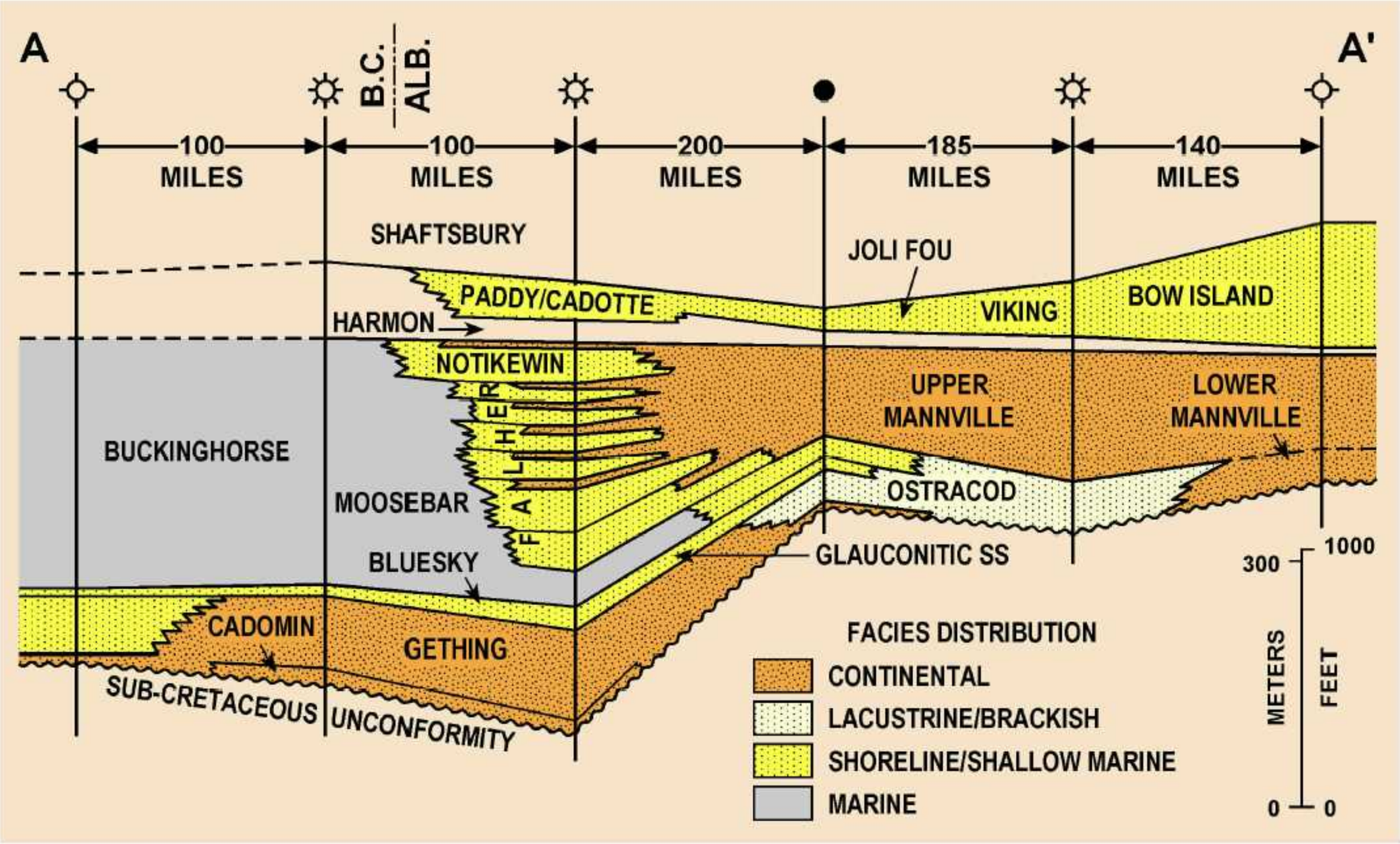


UPPER MANNVILLE LITHOFACIES MAP

RMS045819

Jackson, 1983

REGIONAL FACIES SECTION ALONG THE AXIS OF THE WESTERN CANADA SEDIMENTARY BASIN



RMS840594

ROCK TYPING:
Perm, Archie m and n, Clay Type, Amount and Distribution

BINOCULAR MICROSCOPIC EXAMINATION (AT 10-50X) OF CUTTINGS*

- Estimate of Total Porosity, Micro Porosity, Permeability, Archie "m"
- Estimate of Type, Amount and Distribution of Clay Minerals
- Estimate of Type, Amount and Distribution ofNonclay, Conductive Minerals (e.g. Pyrite)
- Estimate Capillary Curve and Irreducible Water
- Grain Size and Sorting

---

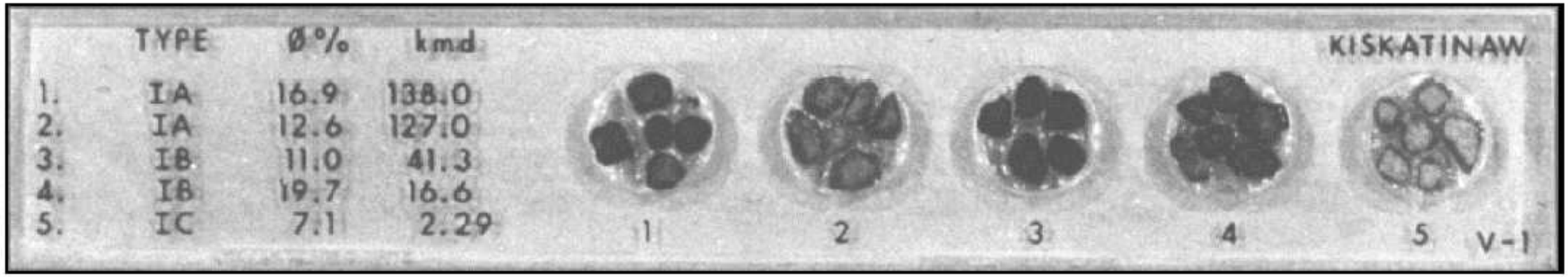
* Tie to Rock Catalogues

PORE - ROCK TYPES FOR SANDSTONE

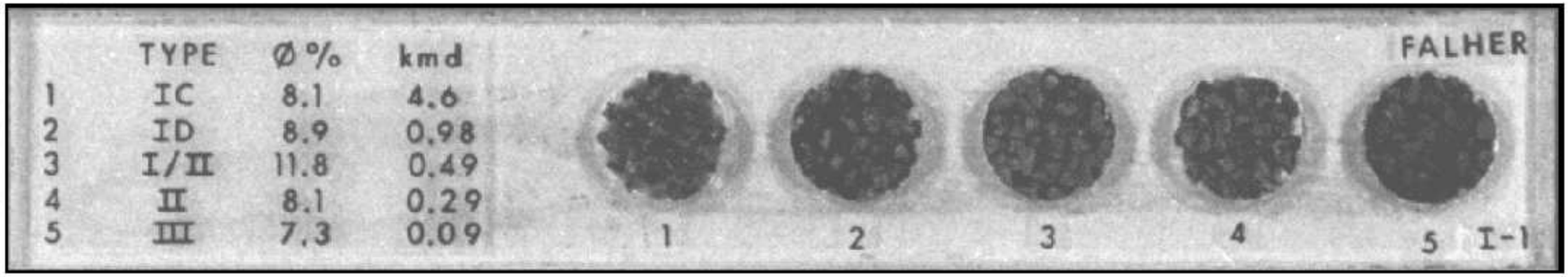
Type	Characteristics of Dry, Freshly Broken Rock Surfaces at 20X Magnification	Remarks
I	• Visible ϕ – very abundant to common • Pinpoint ϕ – very abundant to common • Pore interconnection is visible on many pores • Needle probe can easily dislodge some grains from rock surface and reveal pore	• Reservoir quality rock for gas without natural and/or artificial fracturing (if thick enough) Permeability, md IA >100 IB 10-100 IC 1-10 ID ±0.5-1
II	• Visible ϕ – scattered • Pinpoint ϕ – abundant to common • Needle probe can only occasionally dislodge a grain from rock surface	• Capable of gas production if interlayered with Type I rock, or has natural, open fractures and/or is artificially fractured and is thick enough • Permeability is > ±0.07 to 0.5-1.0 md (Depending on particle size, sorting, and clay mineral content)
III	• Visible ϕ – none to very isolated • Pinpoint ϕ – none to few, scattered pores • Usually very well consolidated and/or pore filled with clays or other pore filling material	• Usually too tight to produce at commercial rate with natural or artificial fractures or when interlayed with Type I rock

RMS861345

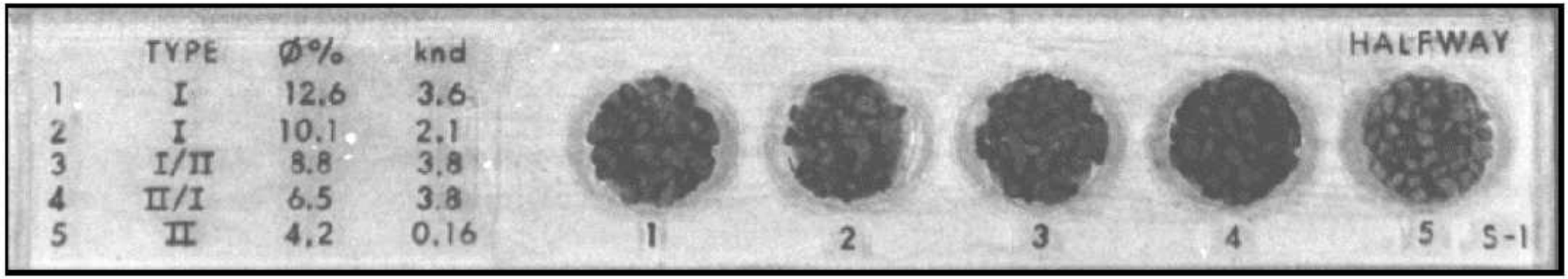
PORE-TYPE COMPARATORS FOR THREE ALBERTA BASIN PRODUCING FORMATIONS



	TYPE	Ø %	kmd
1.	IA	16.9	138.0
2.	IA	12.6	127.0
3.	IB	11.0	41.3
4.	IB	19.7	16.6
5.	IC	7.1	2.29



	TYPE	Ø %	kmd
1	IC	8.1	4.6
2	ID	8.9	0.98
3	I/II	11.8	0.49
4	II	8.1	0.29
5	III	7.3	0.09

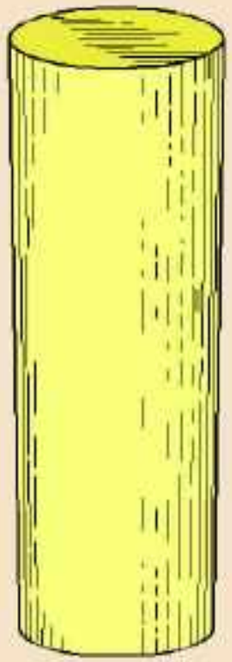


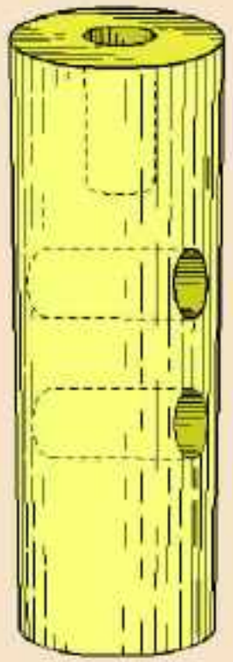
	TYPE	Ø %	knd
1	I	12.6	3.6
2	I	10.1	2.1
3	I/II	8.8	3.8
4	II/I	6.5	3.8
5	II	4.2	0.16

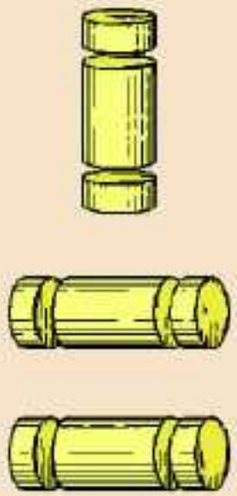
RMS861376

PREPARATION OF PORE TYPE COMPARATORS
LABORATORY TESTS

WHOLE CORE ANALYSES	CONVENTIONAL PLUG ANALYSES	PETROGRAPHIC ANALYSES	COMPARATOR PREPARATION
POROSITY (ϕ), PERMEABILITY (k), SATURATION (S), MODULUS TESTS	(PLUG CUT FROM WHOLE CORE) ϕ, k (STRESSED AND UNSTRESSED), CAPILLARY PRESSURE, FORMATION FACTOR, RELATIVE PERM, ACOUSTIC TESTS, WATER SENSITIVITY	THIN SECTIONS, X-RAY AND RDX, SCANNING ELECTRON MICROSCOPE	PLUGS SELECTED & CRUSHED, PARTICLES SIEVED, PORE-TYPE SAMPLES SELECTED, SAMPLES MOUNTED







RMS964542

LOG ANALYSES

WELL LOG SEARCH FOR BYPASSED PAY

1. Regional scan: “eyeball” scans (pattern recognition of porosity and resistivity logs)

2. Select wells for further analysis on landunleased

3. Exploration phase: these wells undergo more sophisticated analysis by hand calculations. Drillstem tests, water analysis, information on water resistivity, rock type information incorporated into the log analysis.

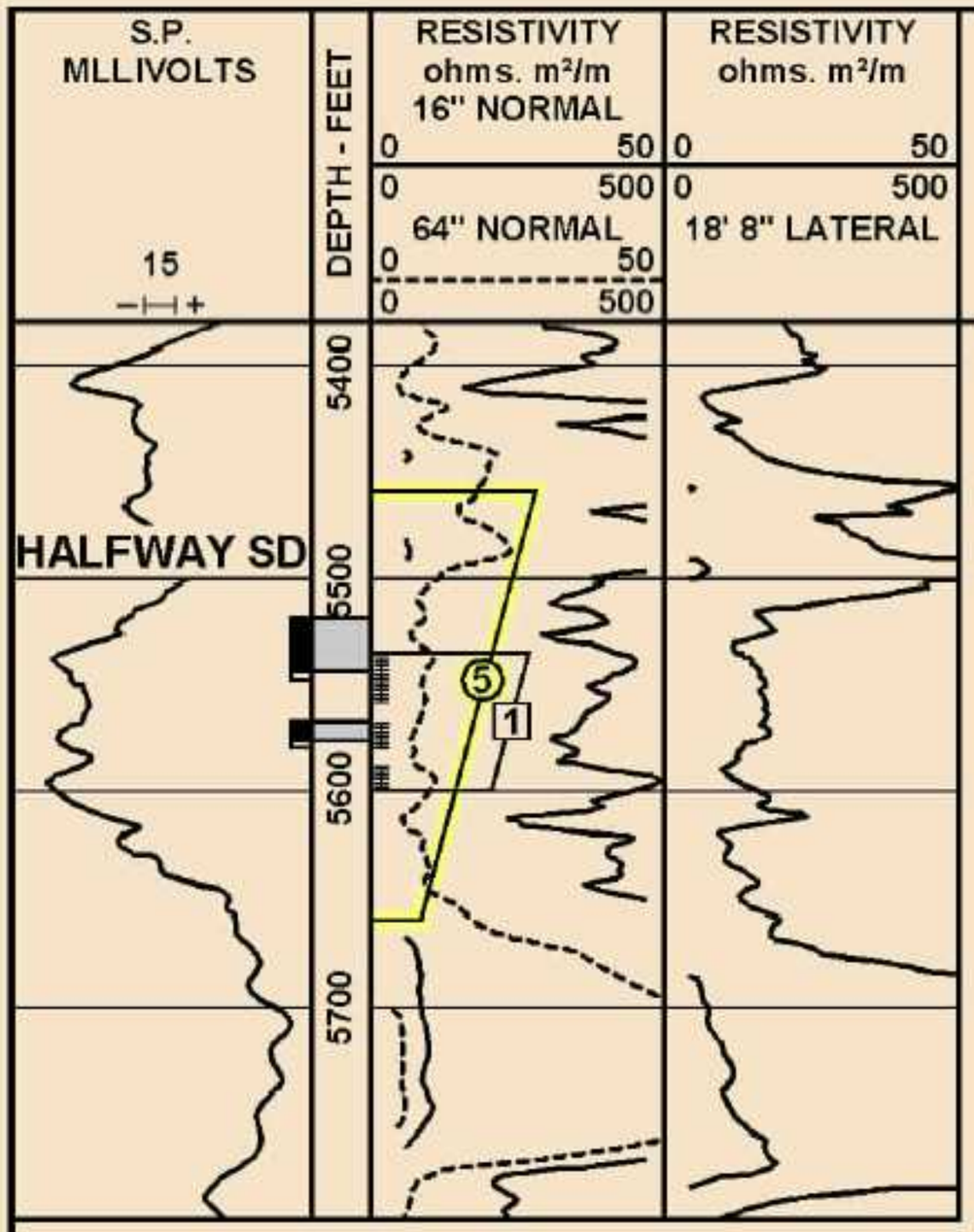
WELL LOG SEARCH FOR BYPASSED PAY

4. Prospect development phase: porosity, water saturation, permeability, lithology, pore space properties, clay content are compared to data from surrounding wells.

5. When a well is drilled, analysis continues. (Well is either a re-entry or a new twin well.)

6. After completion, production logging is used to pinpoint productive and non-productive zones.

HALFWAY FORMATION C-69-J 94-B-16 5535-5600 FEET



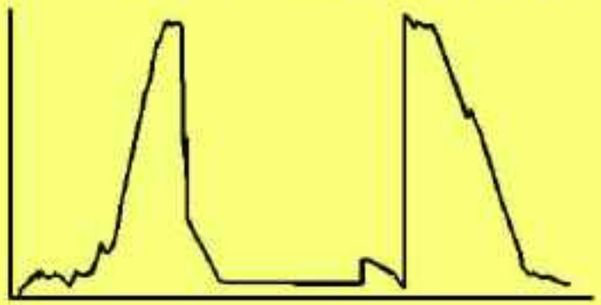
SAMPLE, LOG AND DST / PRODUCTION TEST

1958 DST ⑤: RECOVERED 200 FT SLIGHTLY GAS CUT MUD
S.I.P. INDICATED SOME CLEANING UP

- ISIP= 364 PSI
- FSIP 887 PSI

CORE ANALYSIS:

- ϕ = 9%
- kh = 15 md FT



1975 ANALYSIS:

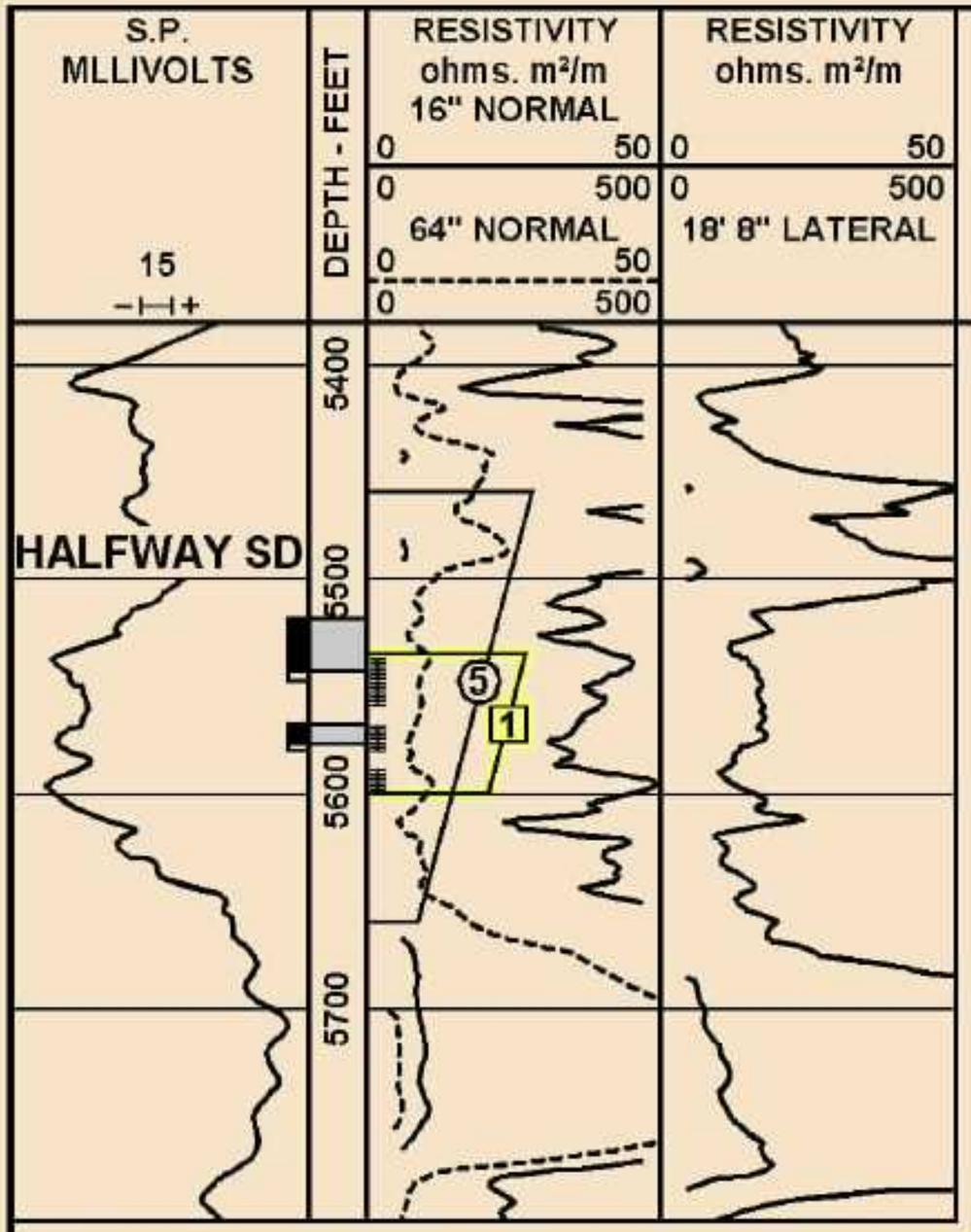
SAMPLES:
- 5510-5540 FT 5-15% TYPE ID
  60-70% TYPE I
- 5560-5600 FT 5-10% TYPE ID
  40-50% TYPE I

LOGS:
- ϕ = 11%
- S_W =14%
- kh = 38 md FT
- PAY = 46 FT

1 WELL RE-ENTERED AND COMPLETED DECEMBER 1975: AOF = 4.6 MMCF/D (AFTER ACID-FRAC)

RMS861342

HALFWAY FORMATION C-69-J 94-B-16 5535-5600 FEET



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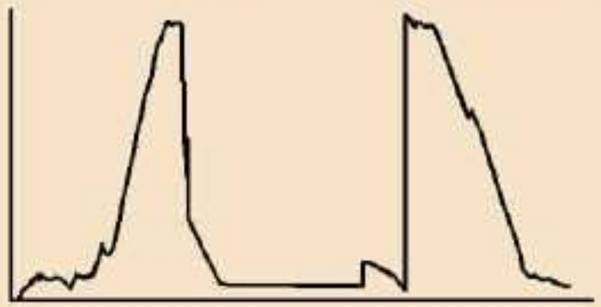

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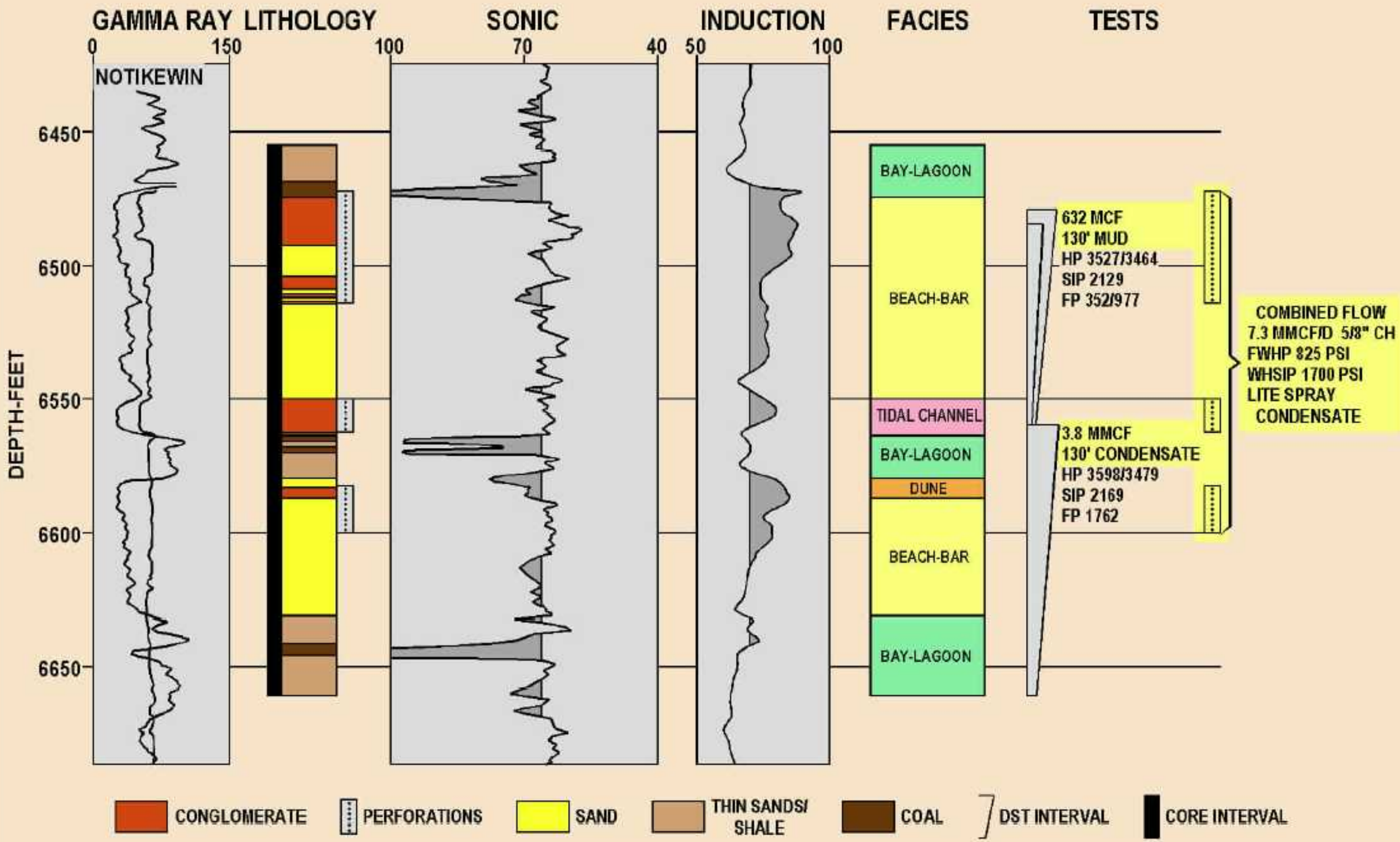
RMS861342

CANHUNTER TEXCAN 6-7-70-11W6

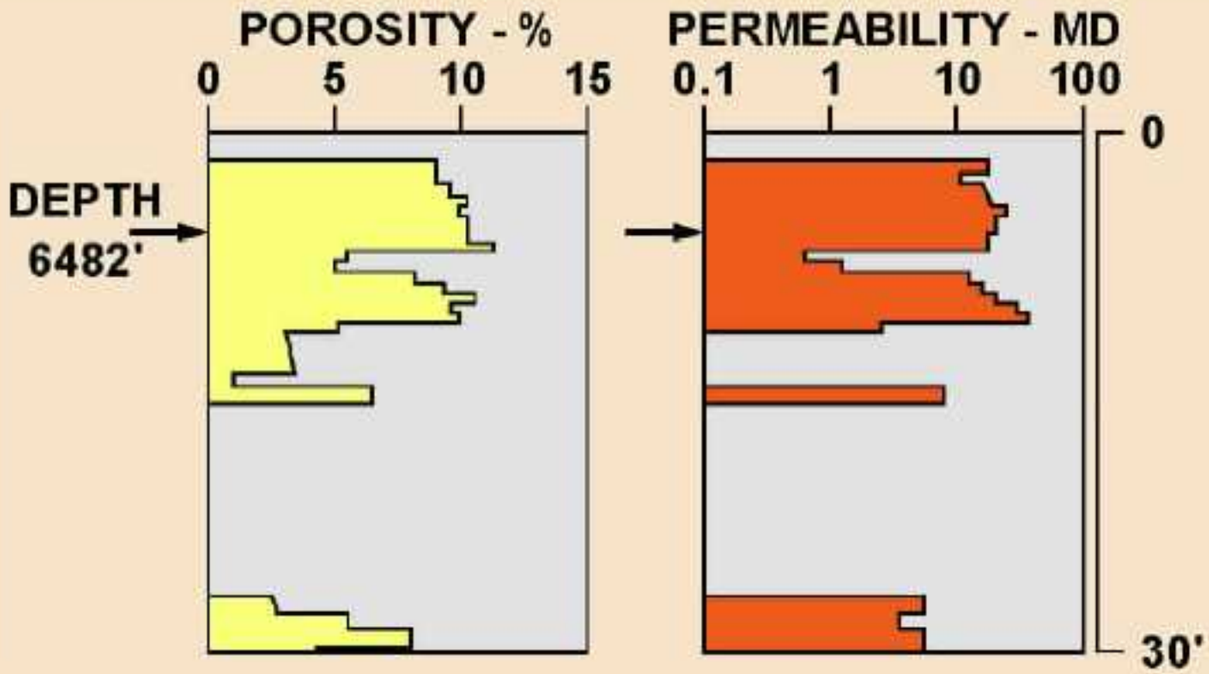


RMS840945

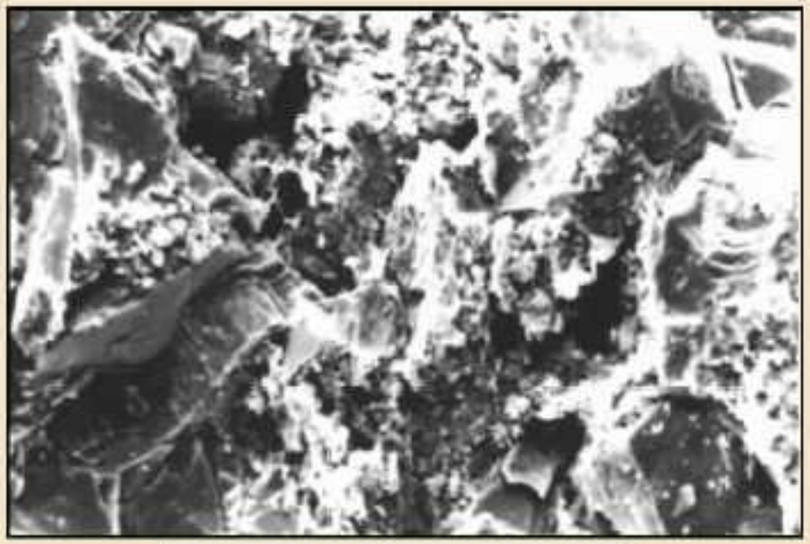
RESERVOIR PROPERTIES:
FALHER CONGLOMERATE AND SANDSTONE

0 INCHES 4

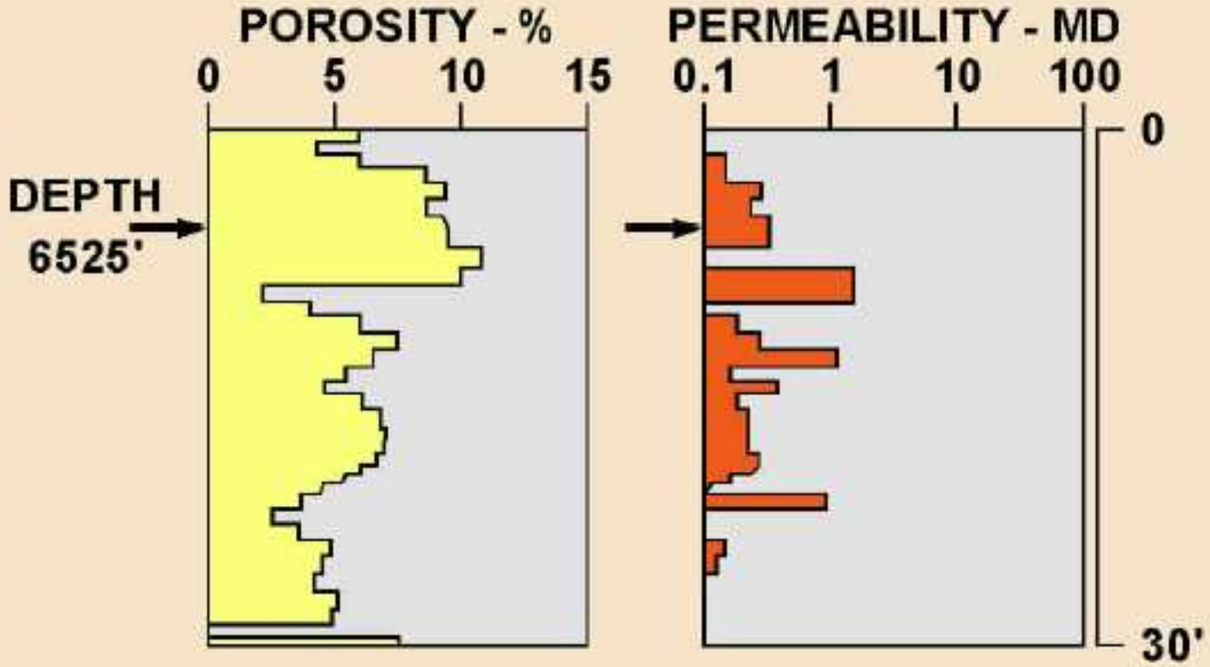
0 MICRONS 500



0 INCHES 4

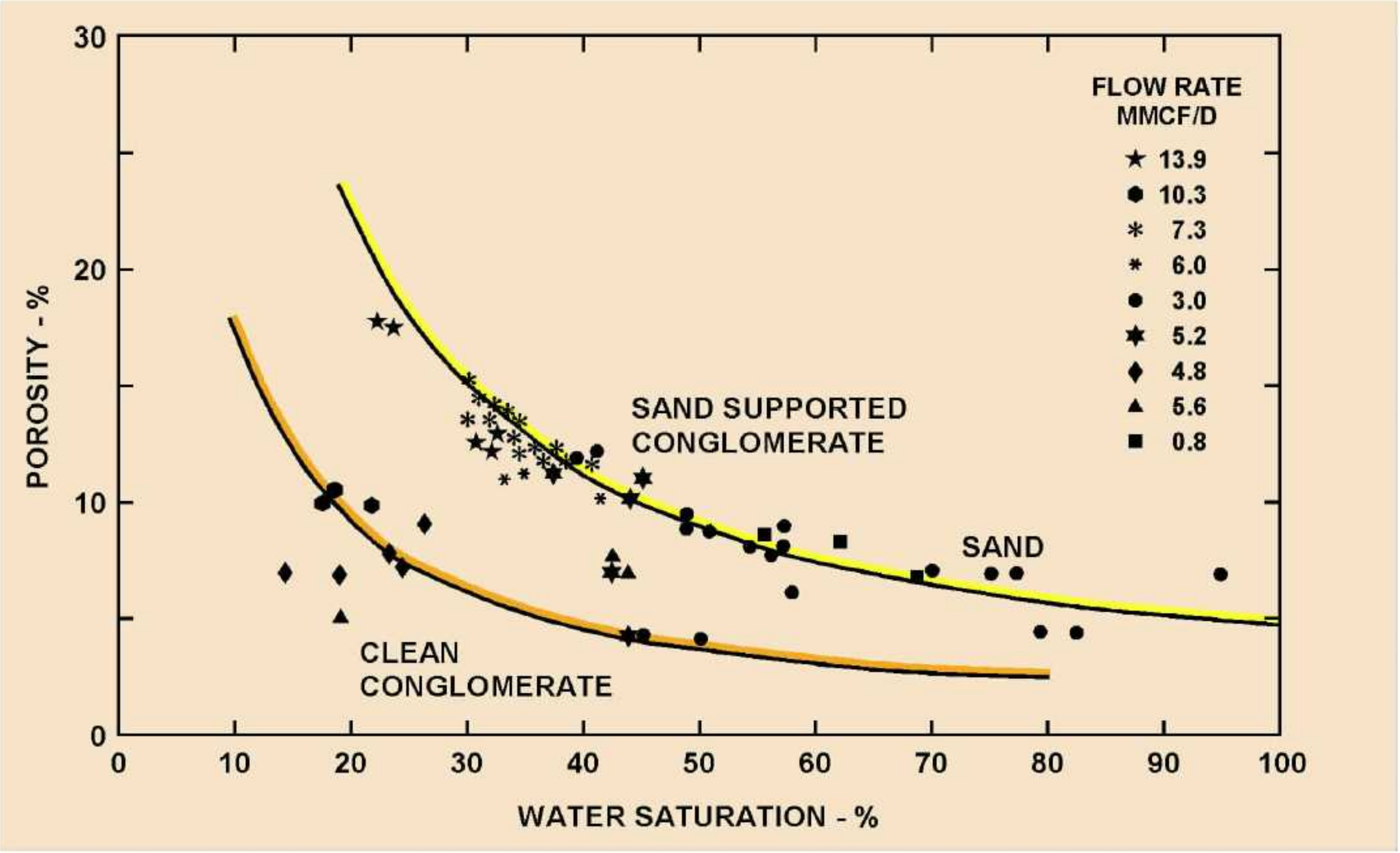


0 MICRONS 500



RMS840923

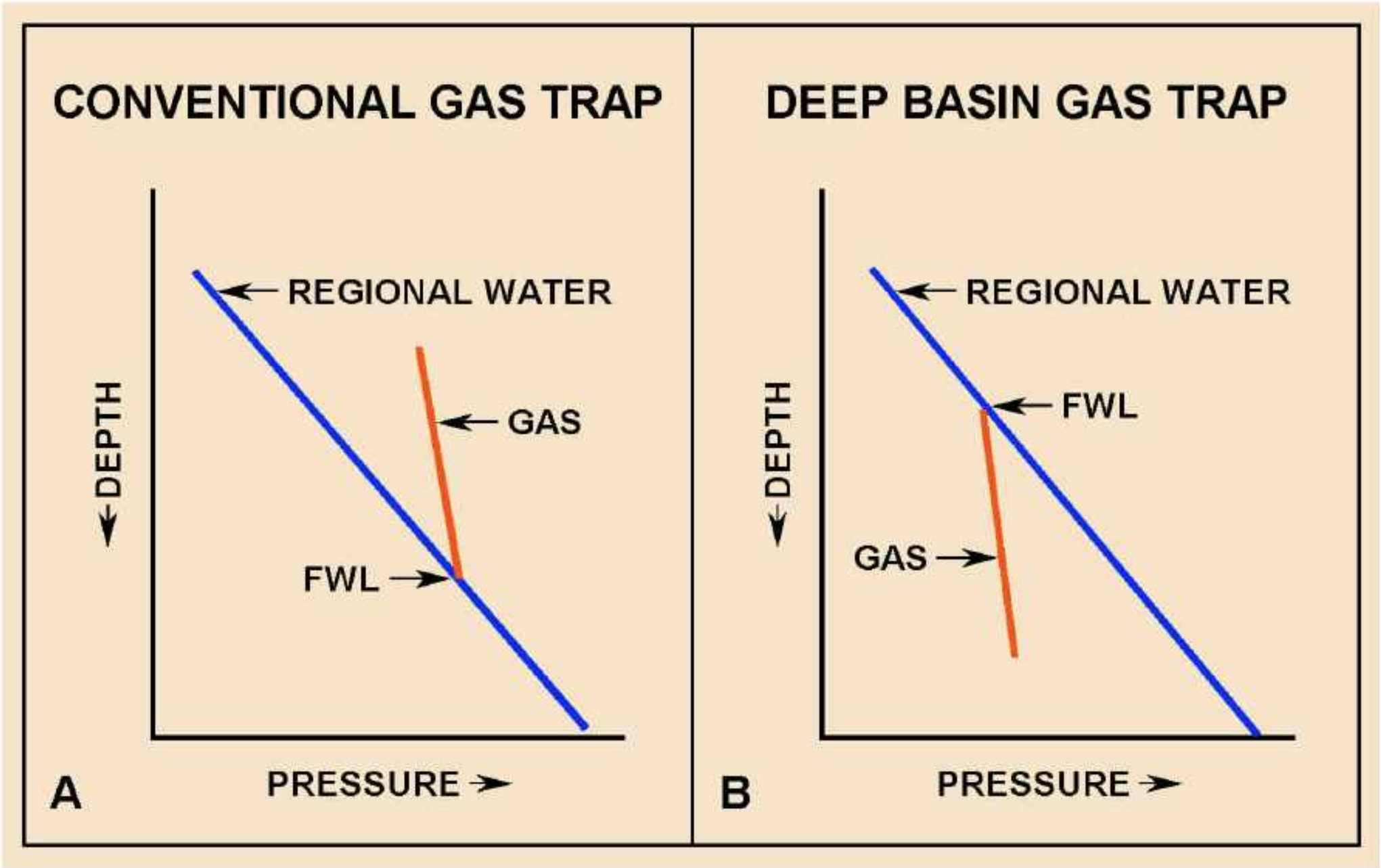
POROSITY vs SATURATION
CONGLOMERATE AND SAND SUPPORTED CONGLOMERATE



RMS045858

PRESSURE PROFILES

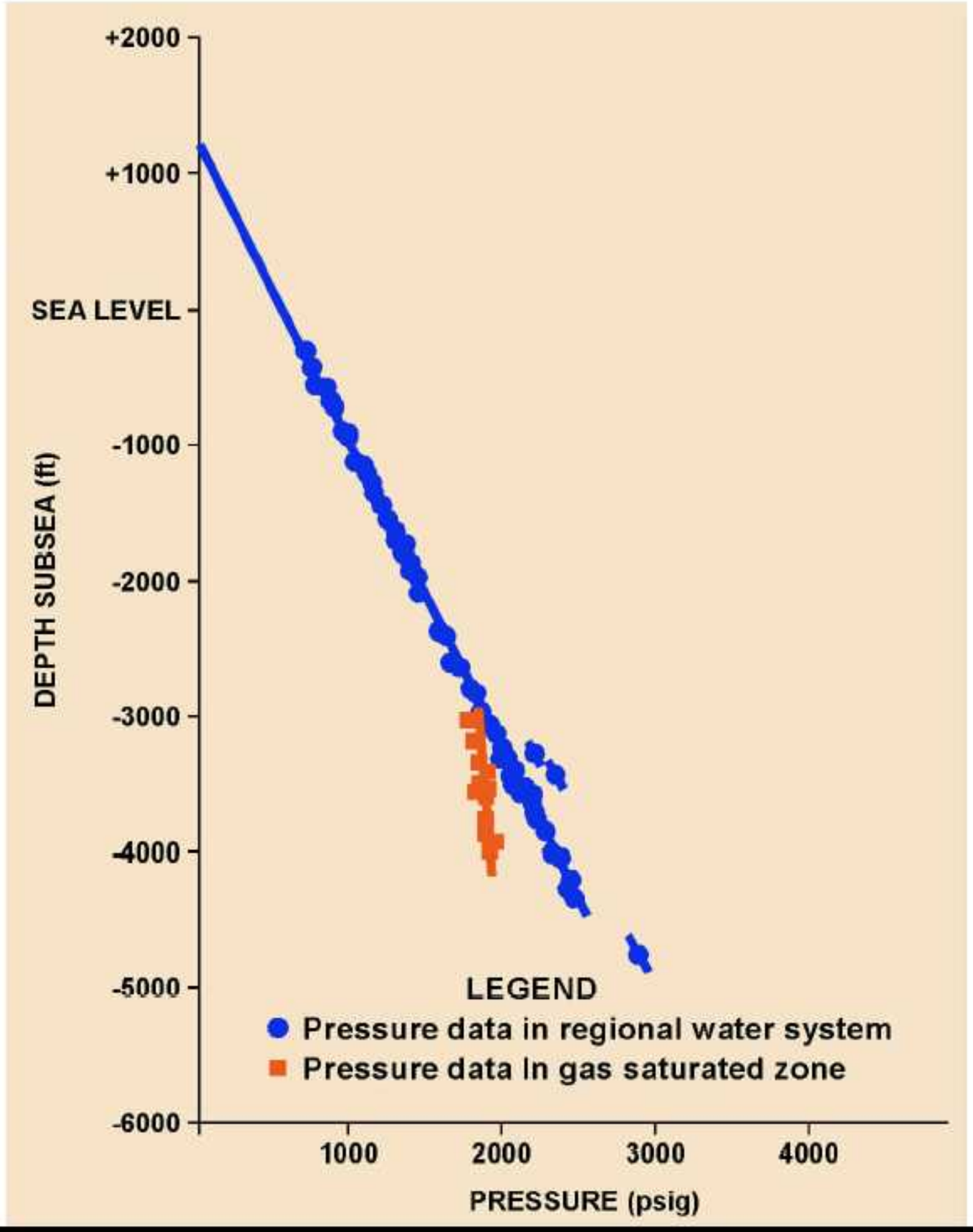
PRESSURE - DEPTH PLOTS
CONVENTIONAL VS DEEP BASIN GAS TRAPS



RMS045803

R.M. Gies, 1984.

PRESSURE - DEPTH PLOT
CADOTTE FORMATION, DEEP BASIN

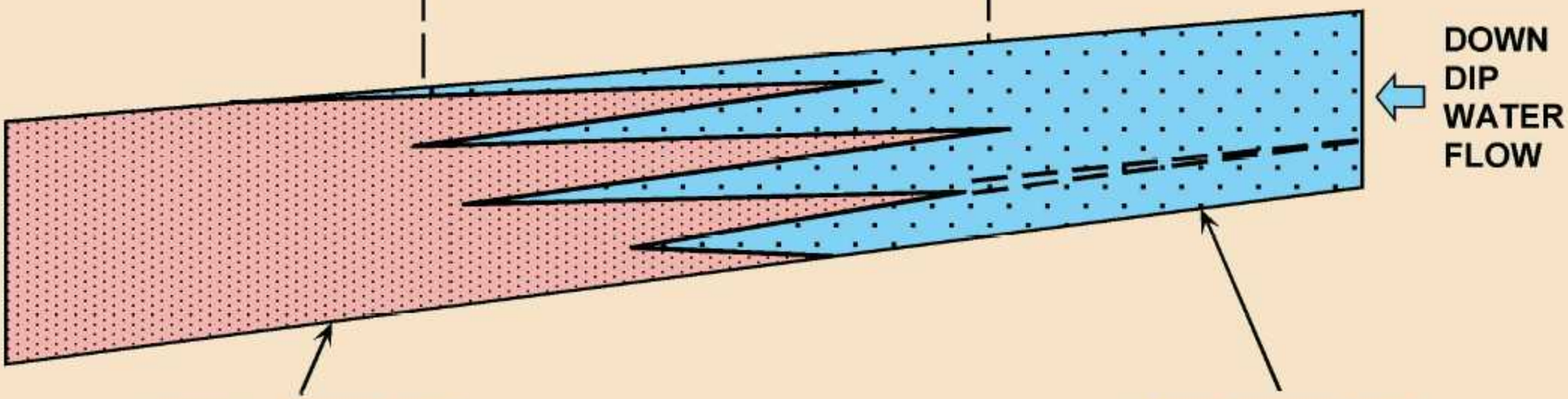


RMS045806

After Davis, 1984

SEAL AND TRAP

GAS – WATER TRANSITION AT TRAP EDGE

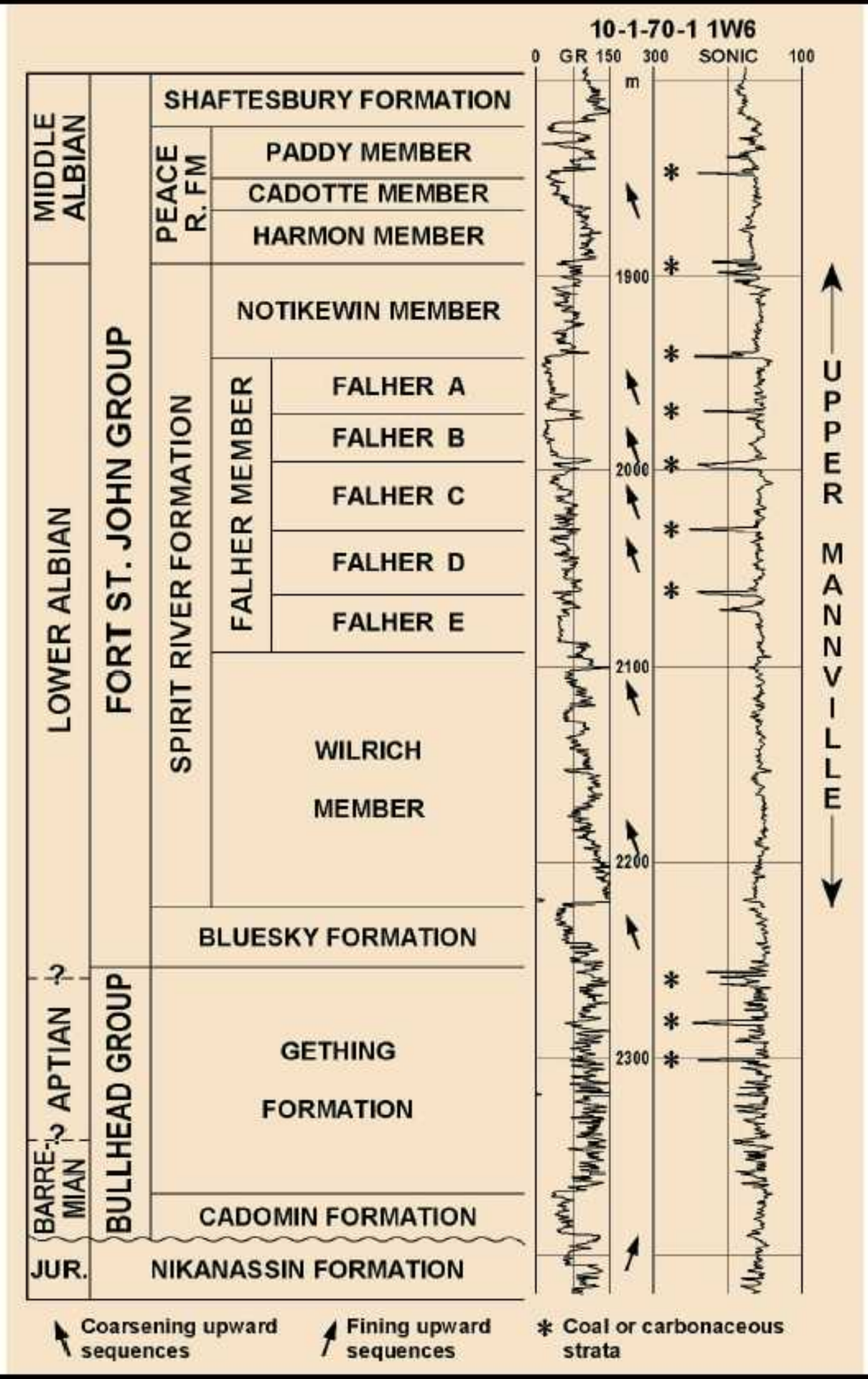


NOTE: HIGH WATER SATURATION IN GAS PHASE
CAUSES DECREASED PERMEABILITY TO GAS
"WATER BLOCK"

RMS045845

Modified after Masters, 1979

TYPE LOG
ELMWORTH FIELD
ALBERTA



RMS045817

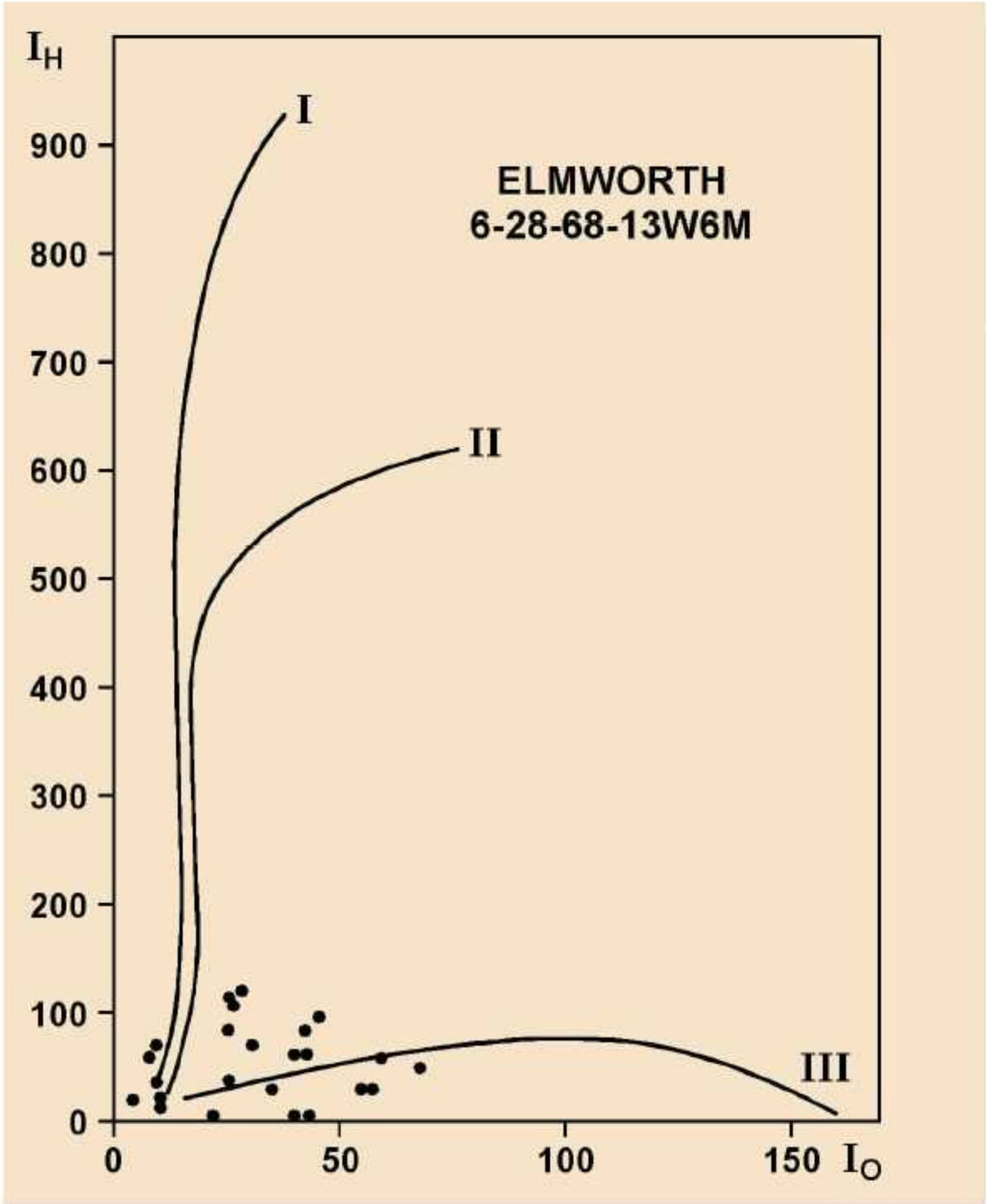
After Smith, Zorn, Sneider, 1984

SOURCE ROCKS

SOURCE ROCKS
(After D. Welte et al., 1983)

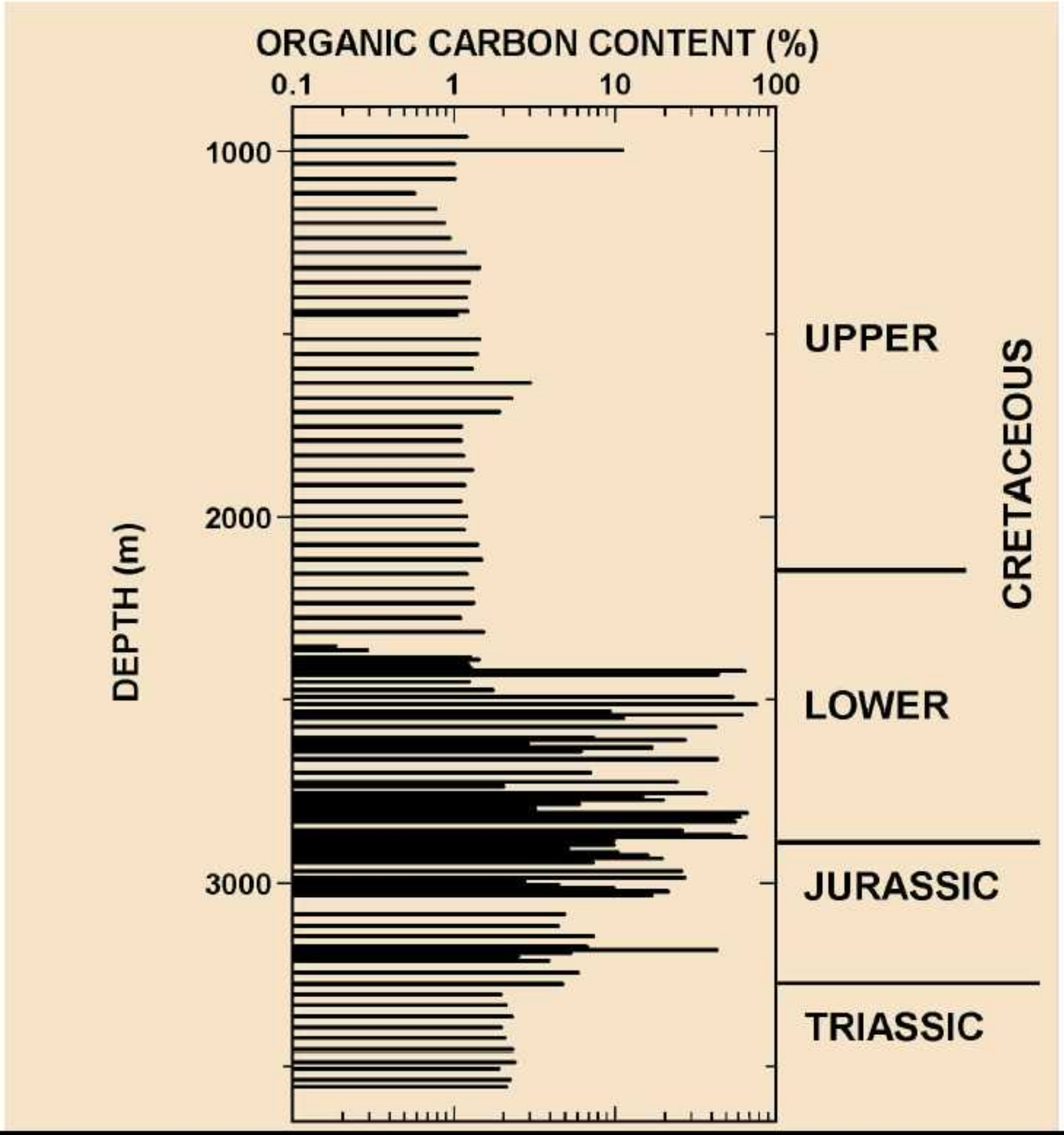
- Geochem. studies show the entire Mesozoic rock section in the Deep-basin is gas saturated.
- Gas saturation decreases rapidly in the shallower part of the rock column and updip toward the east.
- Cretaceous coal measures important gas source (up to 70 m thick).
- Source is mainly Type III kerogen – ideal gas generator.
- Gas is being generated continuously now!

VAN-KREVELEN-TYPE DIAGRAM
ROCK – EVAL PYROLYSIS



RMS045815

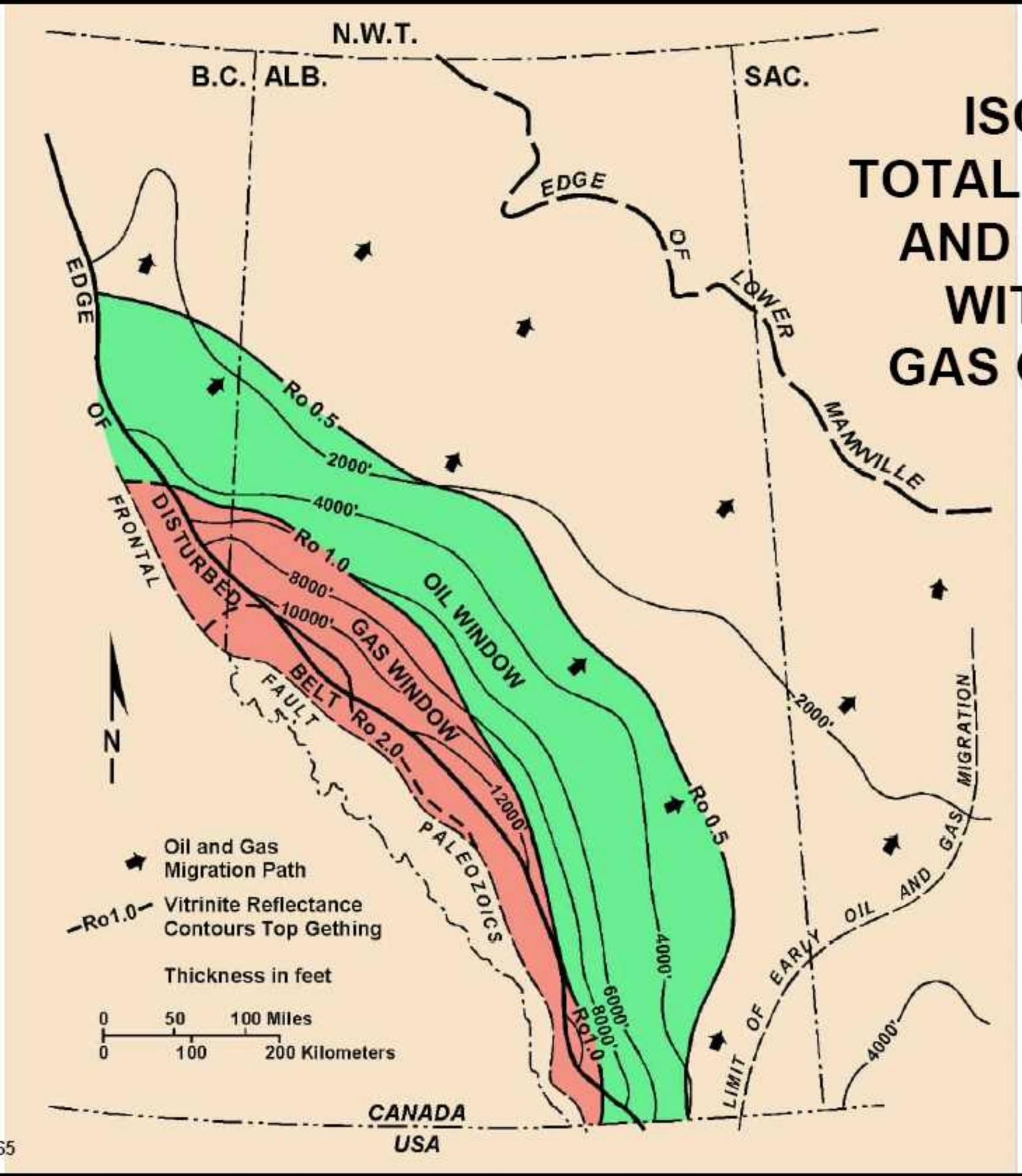
ELMWORTH 6-28-68-13W6M



RMS045814

After Welte, et al, 1984

ISOPACH OF TOTAL CRETACEOUS AND PALEOCENE WITH OIL AND GAS GENERATING AREAS

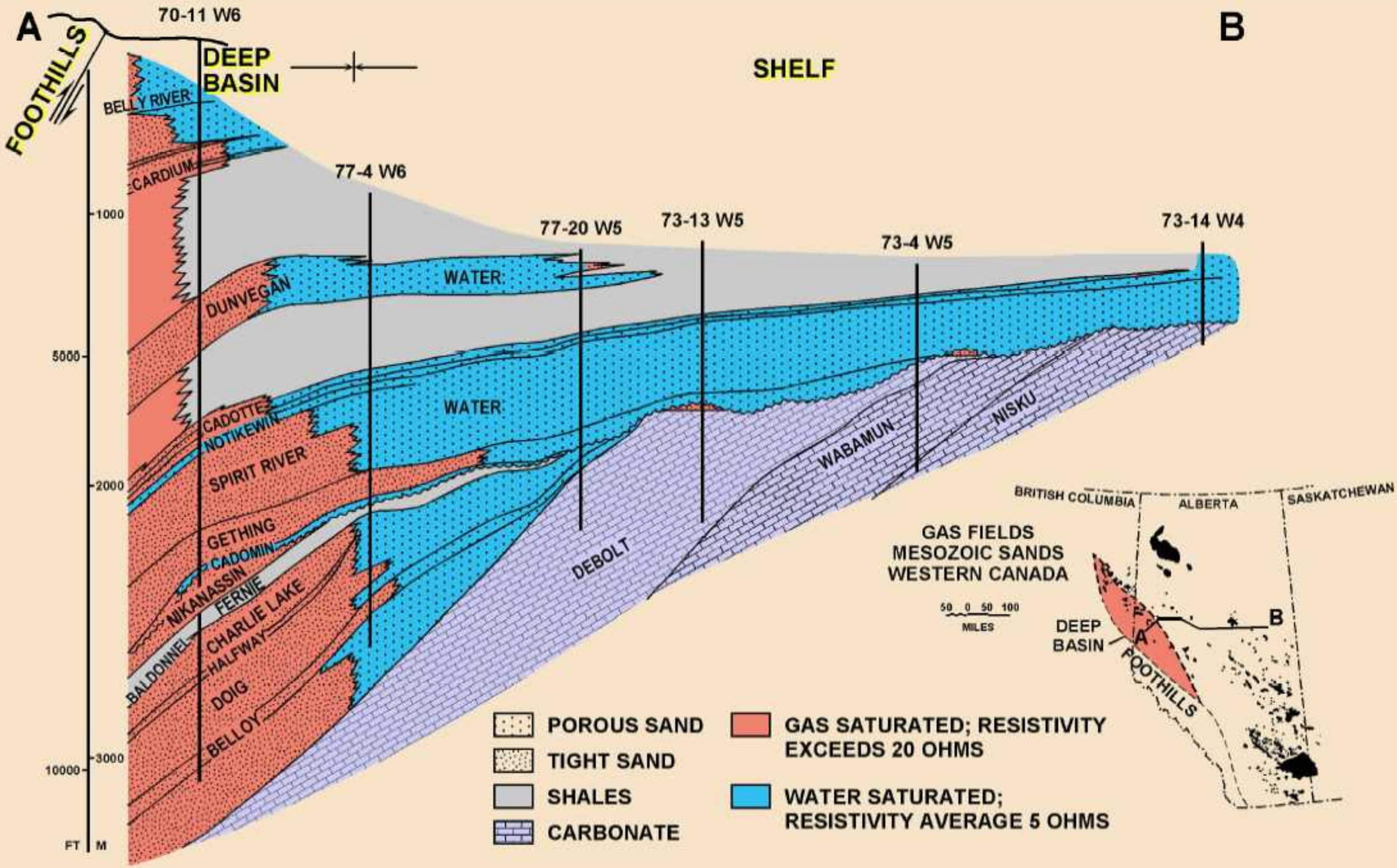


RMS995265

After Masters, 1984

RESERVES

DEEP BASIN GAS TRAP



RMS045795

PRODUCTION AND RESERVES

PRODUCTION:

> 5 TCF GAS
> 1 BILLION BBLS CONDENSATE + OIL

RESERVES:

> 5 TCF GAS

RESOURCE:

10s OF TCF GAS

PROVED RESERVES

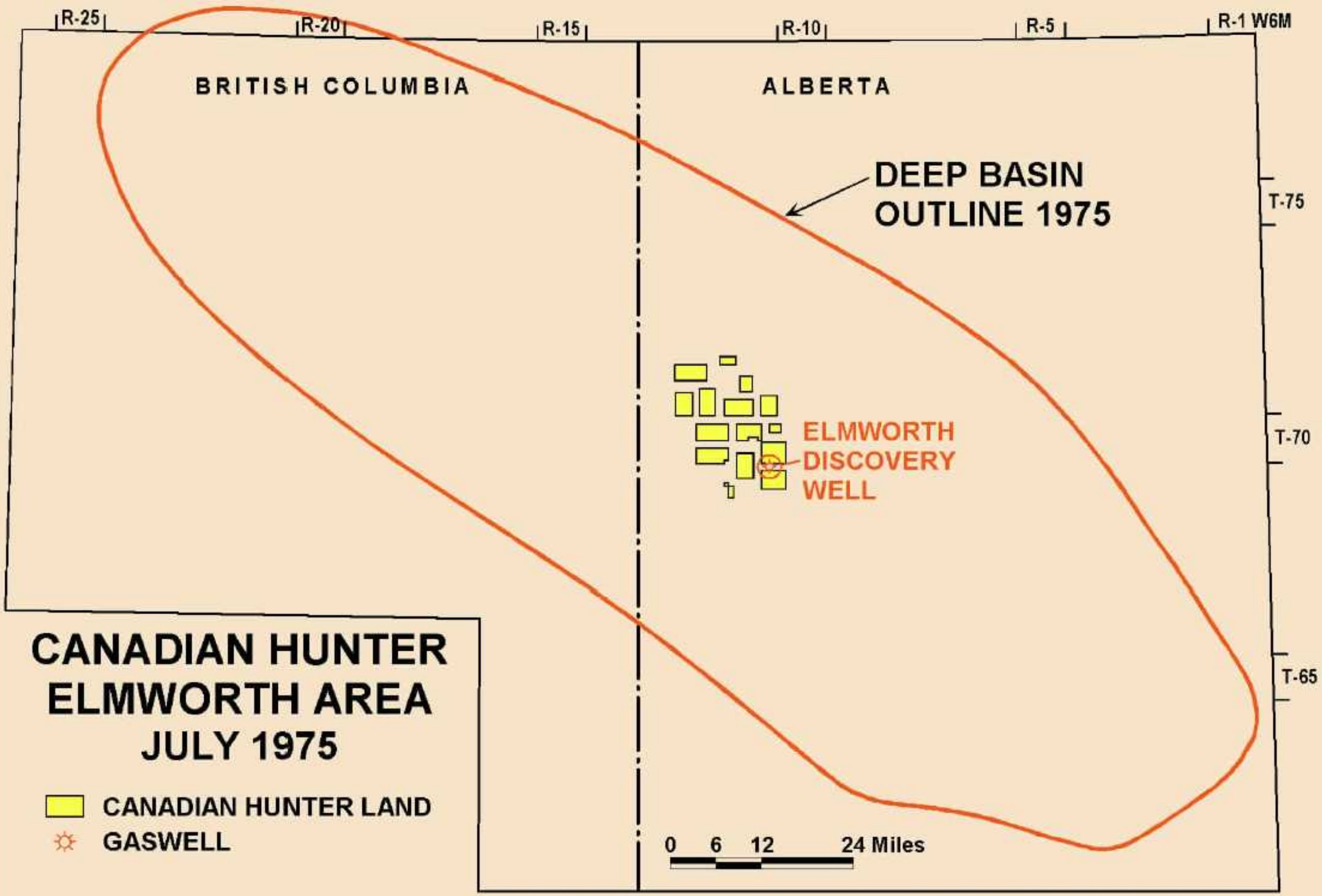
Proven reserves are volumes that are considered recoverable with a high degree of certainty under anticipated operating and economic conditions. Proved reserves may be assigned to both developed and undeveloped lands.

PROBABLE RESERVES

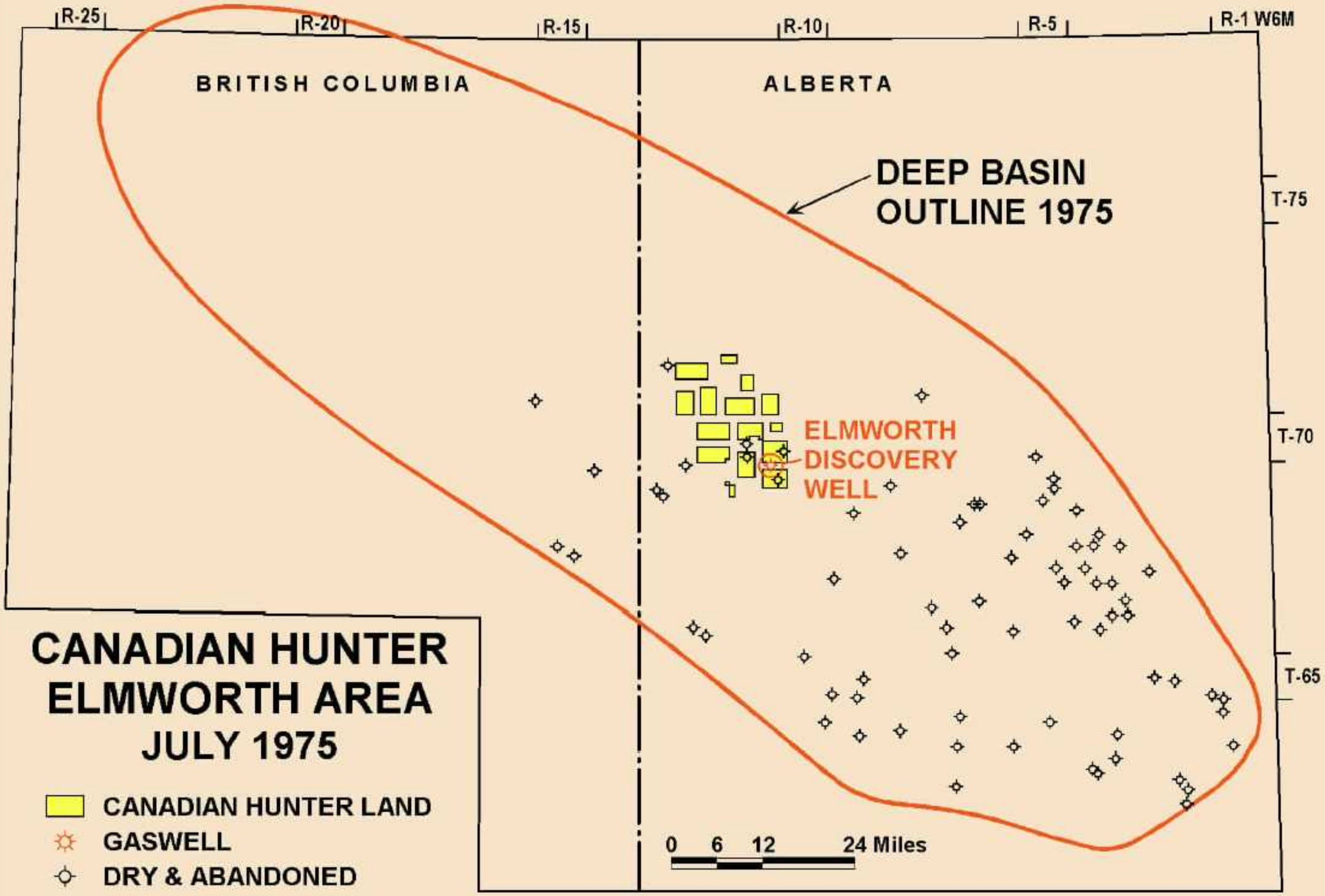
Probable reserves are volumes that may be recovered from lands in the vicinity of proven reserves but where there is some degree of geological, engineering, operational or economic risk.

RESOURCES

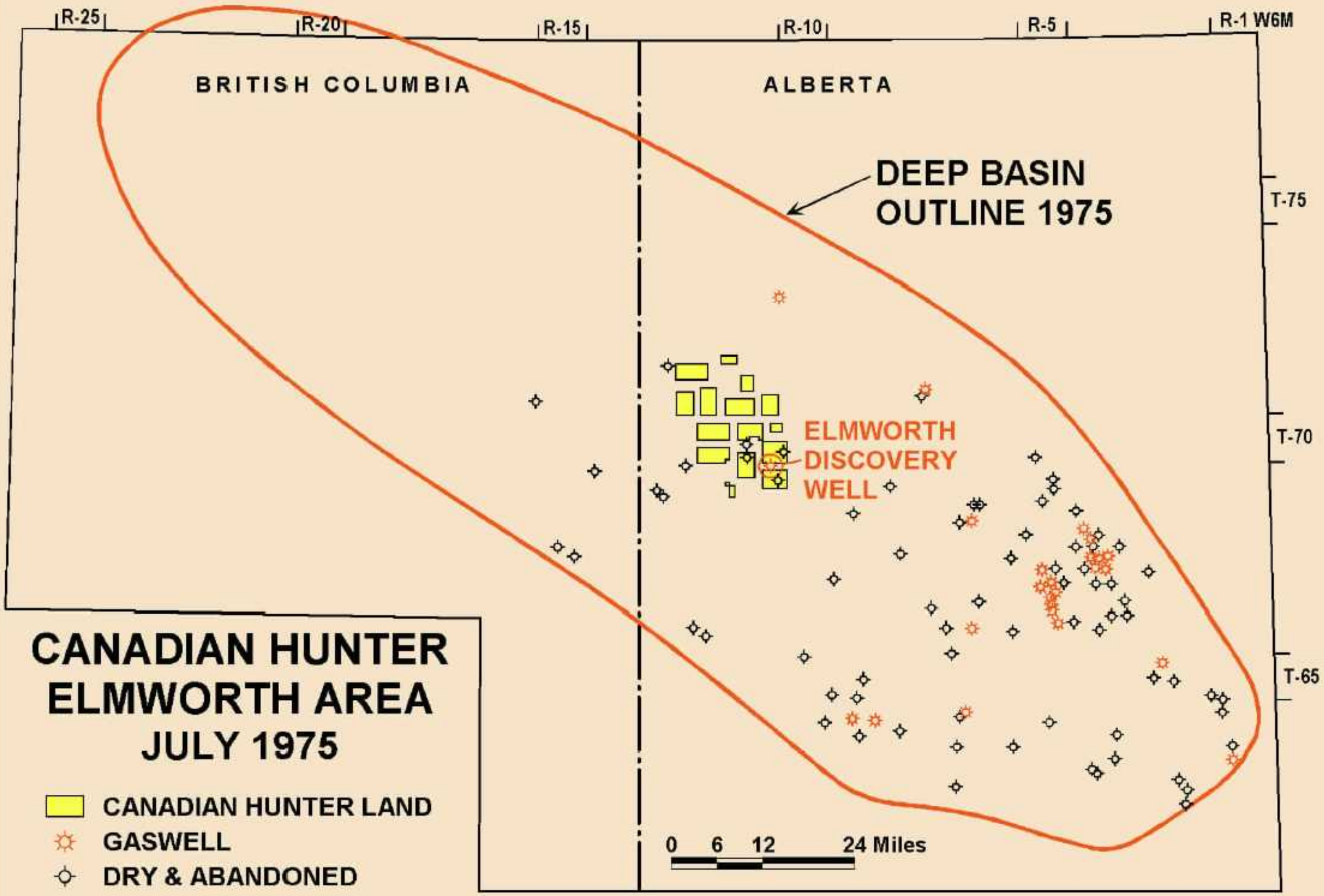
Hydrocarbons in a producing trend that require improved technology and/or significant price increase to be recovered


R-25
R-20
R-15
R-10
R-5
R-1 W6M
BRITISH COLUMBIA
ALBERTA
DEEP BASIN
OUTLINE 1975
T-75
T-70
T-65
ELMWORTH
DISCOVERY
WELL
CANADIAN HUNTER
ELMWORTH AREA
JULY 1975
CANADIAN HUNTER LAND
GASWELL
0 6 12 24 Miles

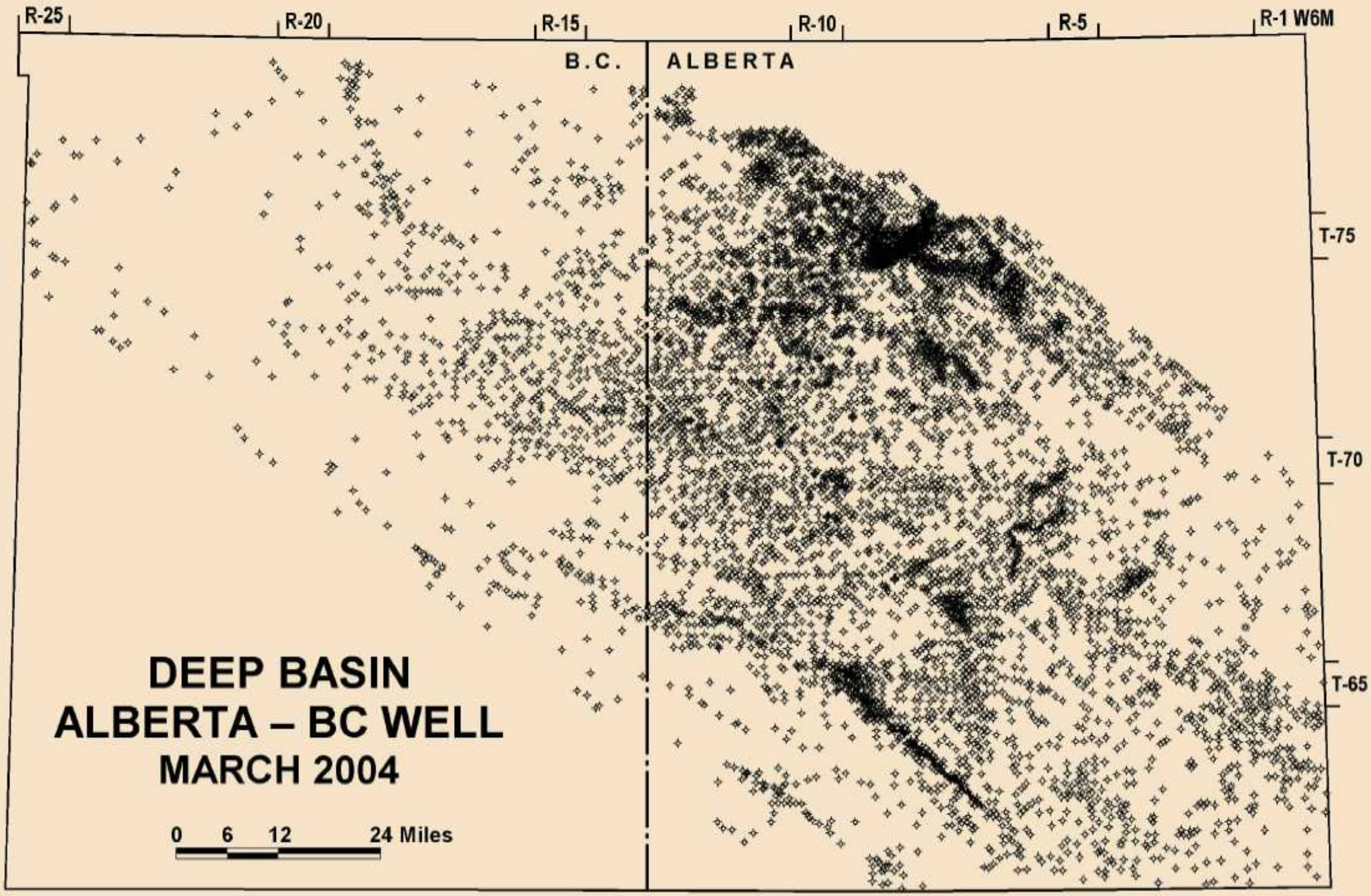
RMS045810


R-25
R-20
R-15
R-10
R-5
R-1 W6M
BRITISH COLUMBIA
ALBERTA
DEEP BASIN
OUTLINE 1975
T-75
T-70
T-65
ELMWORTH
DISCOVERY
WELL
0 6 12 24 Miles
CANADIAN HUNTER
ELMWORTH AREA
JULY 1975
CANADIAN HUNTER LAND
GASWELL
DRY & ABANDONED

RMS045811


R-25
R-20
R-15
R-10
R-5
R-1 W6M
BRITISH COLUMBIA
ALBERTA
DEEP BASIN
OUTLINE 1975
T-75
T-70
T-65
ELMWORTH
DISCOVERY
WELL
0 6 12 24 Miles
CANADIAN HUNTER
ELMWORTH AREA
JULY 1975
CANADIAN HUNTER LAND
GASWELL
DRY & ABANDONED

RMS045812


R-25
R-20
R-15
R-10
R-5
R-1 W6M
B.C.
ALBERTA
T-75
T-70
T-65
DEEP BASIN
ALBERTA – BC WELL
MARCH 2004
0 6 12 24 Miles

RMS045820

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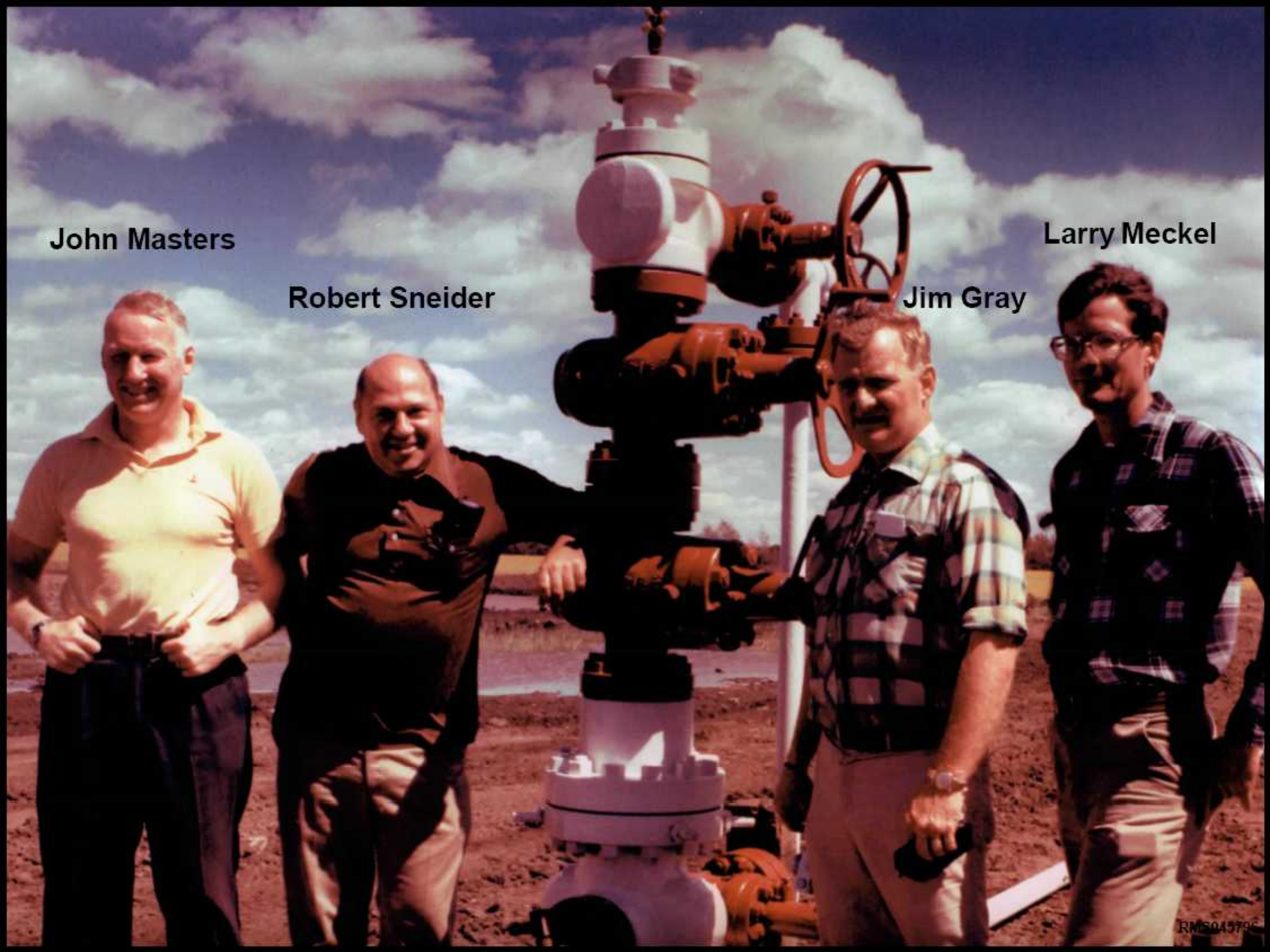
ELMWORTH DISCOVERY
RMS0457


John Masters
Robert Sneider
Jim Gray
Larry Meckel

DRILLING / COMPLETION
RESERVOIR ENGINEERING
LAND STRATEGY

LESSONS LEARNED

SOME COMMON REASONS FOR FAILURES

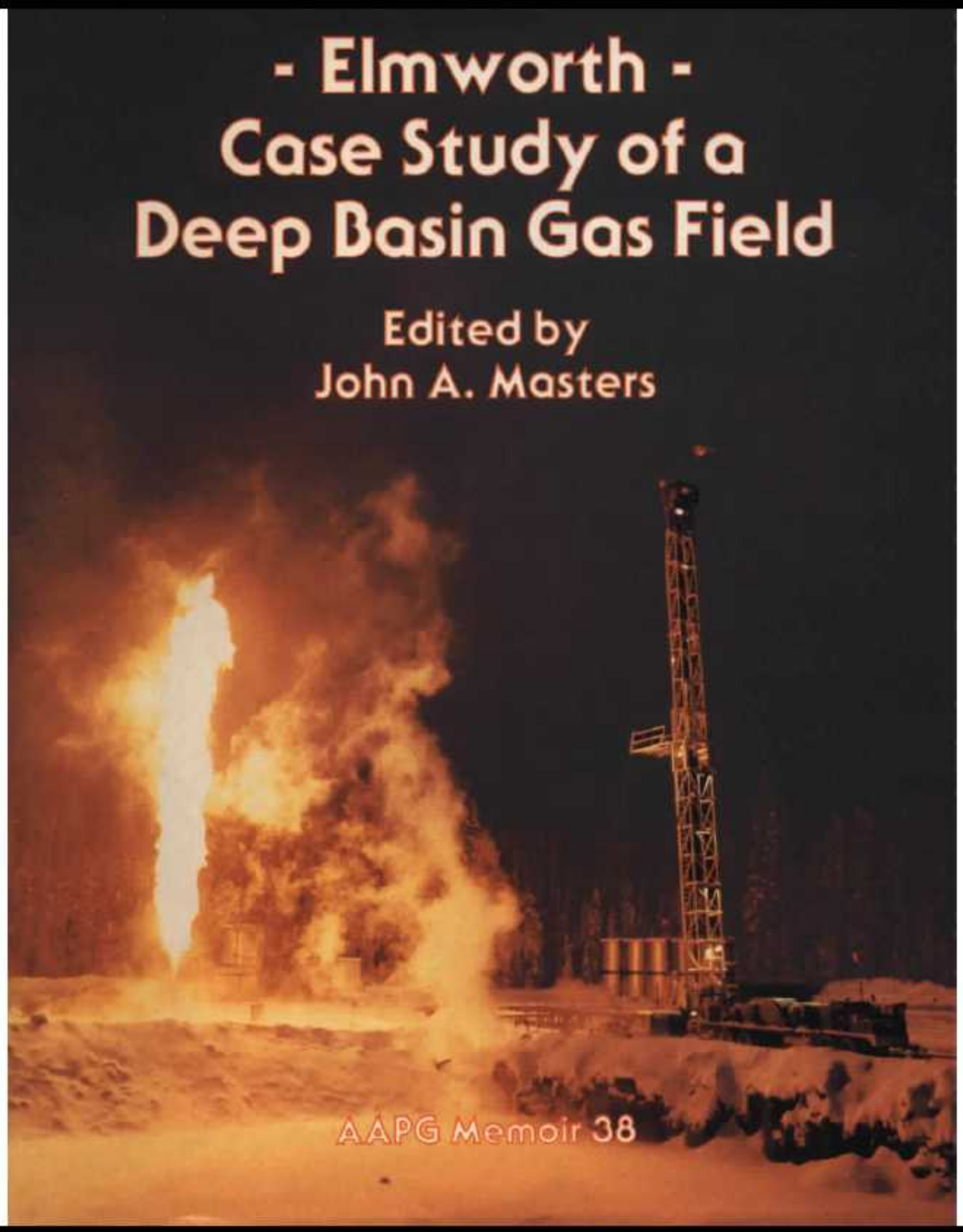
- Poor Integration of Geoscience and Engineering Data
- Incorrect Petrophysical Models
  - Effect of Conductive Minerals (Clays, Pyrite)
  - Incorrect Archie “m” and “n”
- Understanding Connate Water Saturation (S_w) vs Irreducible Water Saturation (S_{wirr}) Plus S_w
- Recognize Damaged Zones vs Low Perm. Zones

SOME COMMON REASONS FOR FAILURES

- Recognize Pressure Seals' Role in Trapping
- Recognize Lower Limits of Pay Using ϕ and S_w Cutoffs Considering Stimulation Procedures
- Recognize Opportunities, Technical Improvements and Economic Trends from Similar Basins and Geology that can Apply to the Play / Prospect
- No Sales Outlet (e.g. Pipelines)

- Elmworth -
Case Study of a Deep Basin Gas Field

Edited by
John A. Masters



AAPG Memoir 38

RMS995269

END