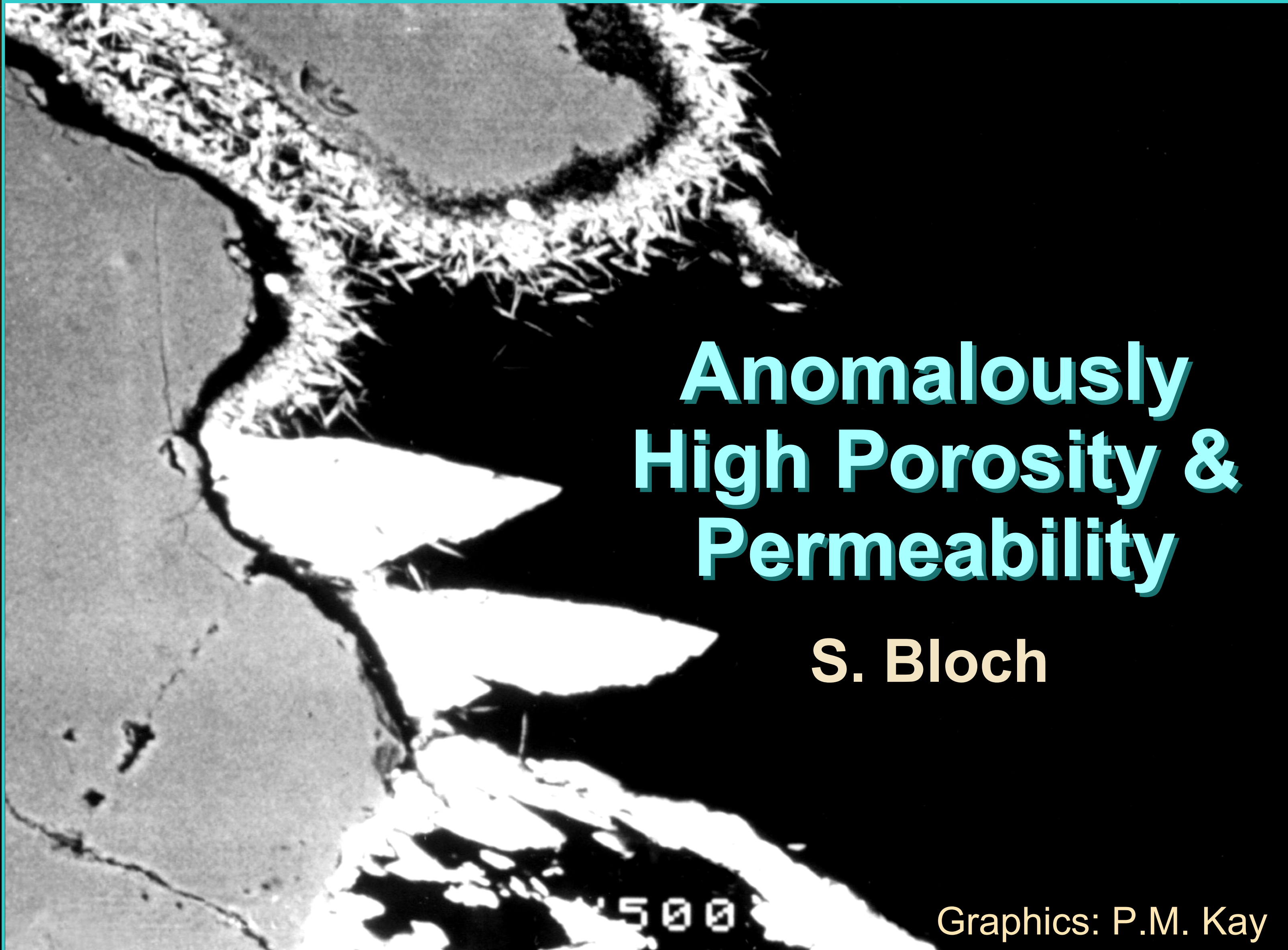
Anomalously High Porosity & Permeability

S. Bloch



Graphics: P.M. Kay

Anomalously High p&p

- Quantitative Definition
- Origin and Predictability
  - Grain Coats & Grain Rims
    - Chlorite Coats
    - Quartz Coats
    - Clay Rims
  - Early Hydrocarbon Emplacement
  - Early Overpressure
  - Secondary Porosity

Conclusions

- **anomalous porosity** - statistically higher than porosity values occurring in "typical" sandstone reservoirs of a given lithology, age, and burial / temperature history

- evaluation of anomalous p&p preserved by **chlorite coats** is a two-step process:
  - evaluation of the likelihood of occurrence of chlorite coats as a function of sediment provenance and depositional facies
  - diagenetic modeling to determine the constraints required to preserve economically viable p&p

Conclusions

- Impact of hydrocarbon emplacement on p&p can be quantified, prior to drilling, by integration of basin modeling and reservoir quality modeling

- p&p preservation due to fluid overpressure can be quantified, prior to drilling, by integration of basin modeling and reservoir quality modeling

Conclusions

- **Secondary porosity**
  - **Unquestionable ubiquity**
  - **Importance overemphasized**
  - **Effect on reservoir quality prediction**
    - **Extent of preservation controlled by the same geological parameters as primary p&p**
    - **Implicitly accounted for by calibration data sets used in empirical predictions**
    - **Limited impact on reservoir scale - “redistributional”, not effective**

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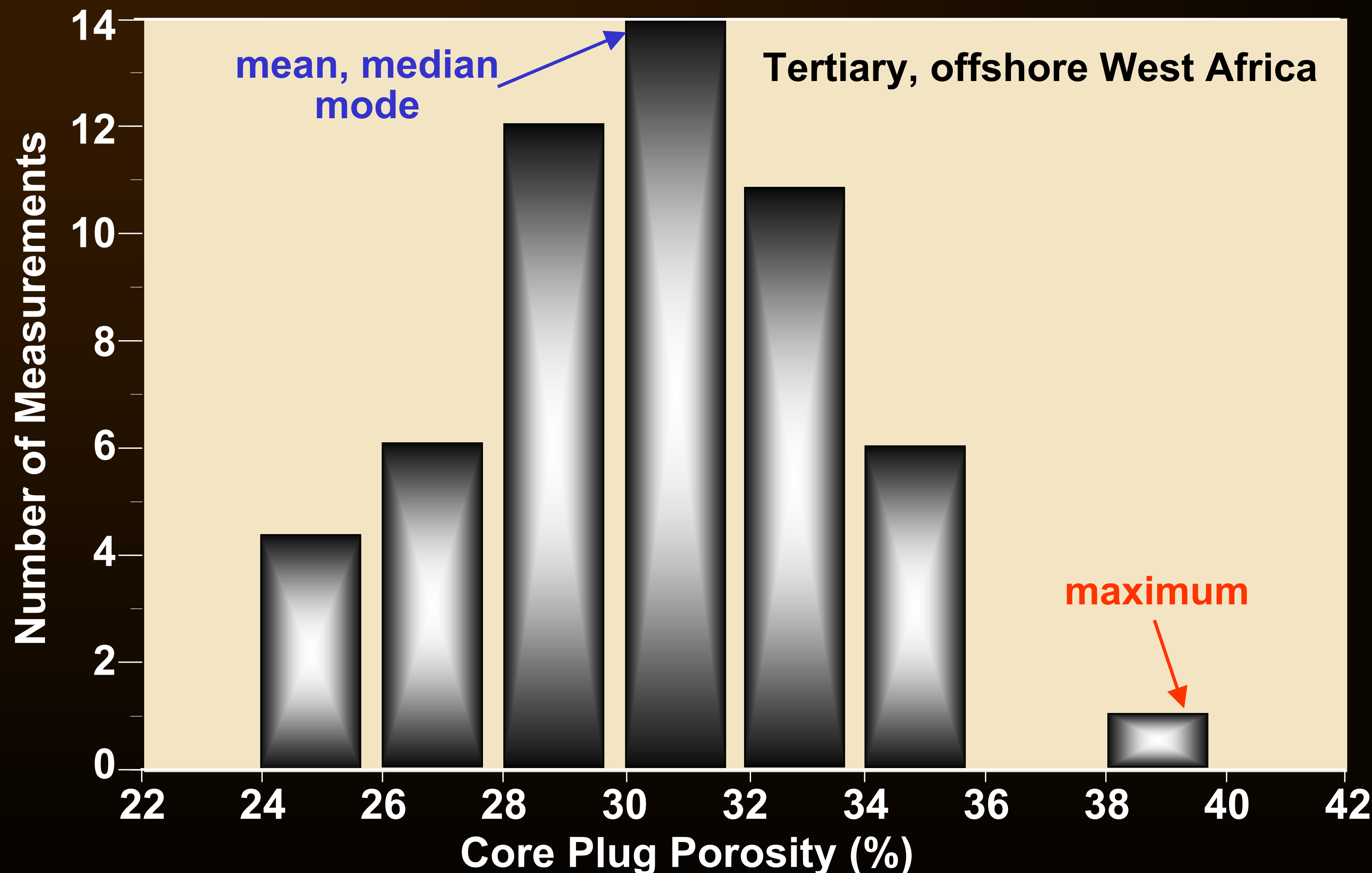
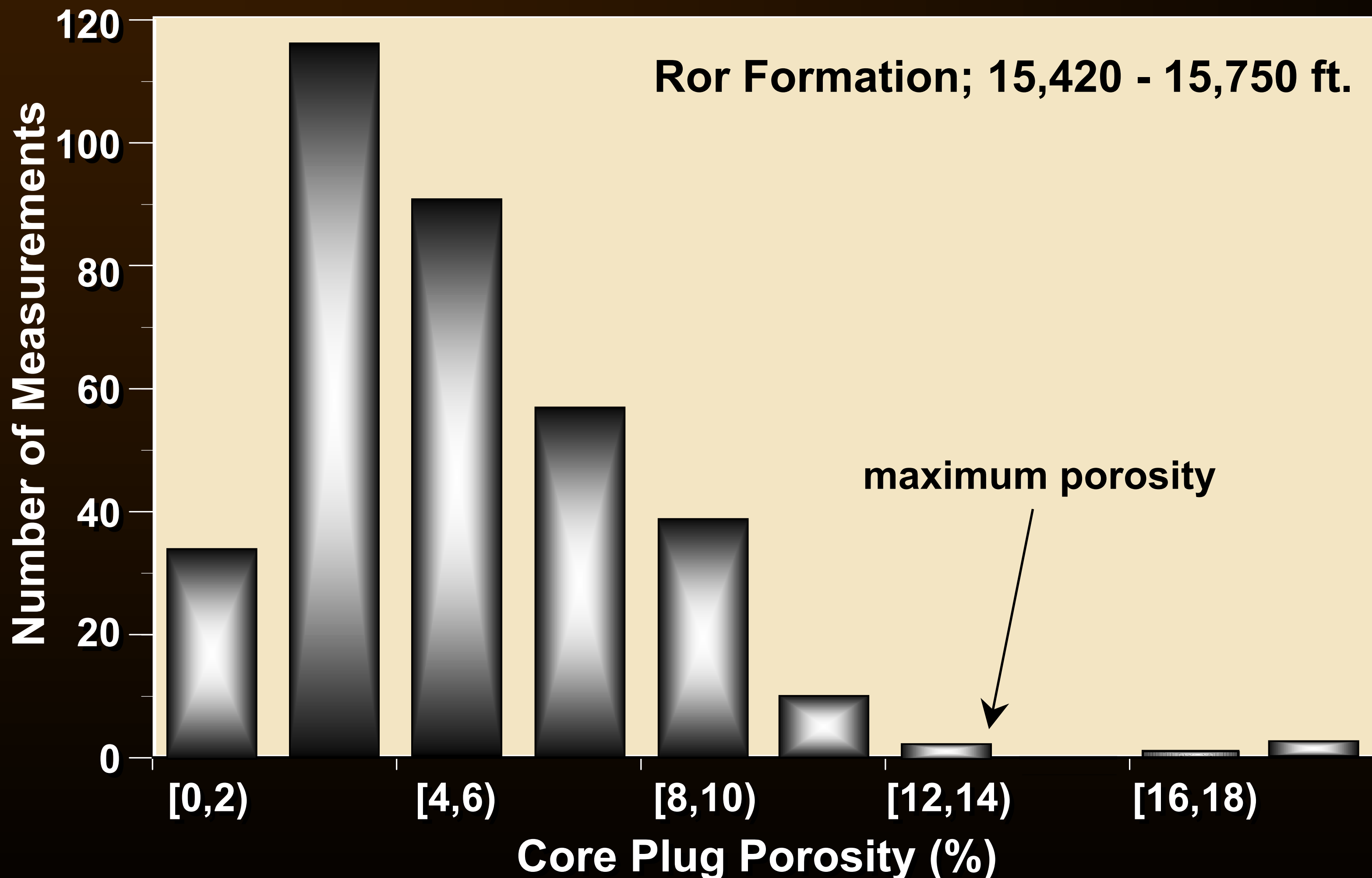
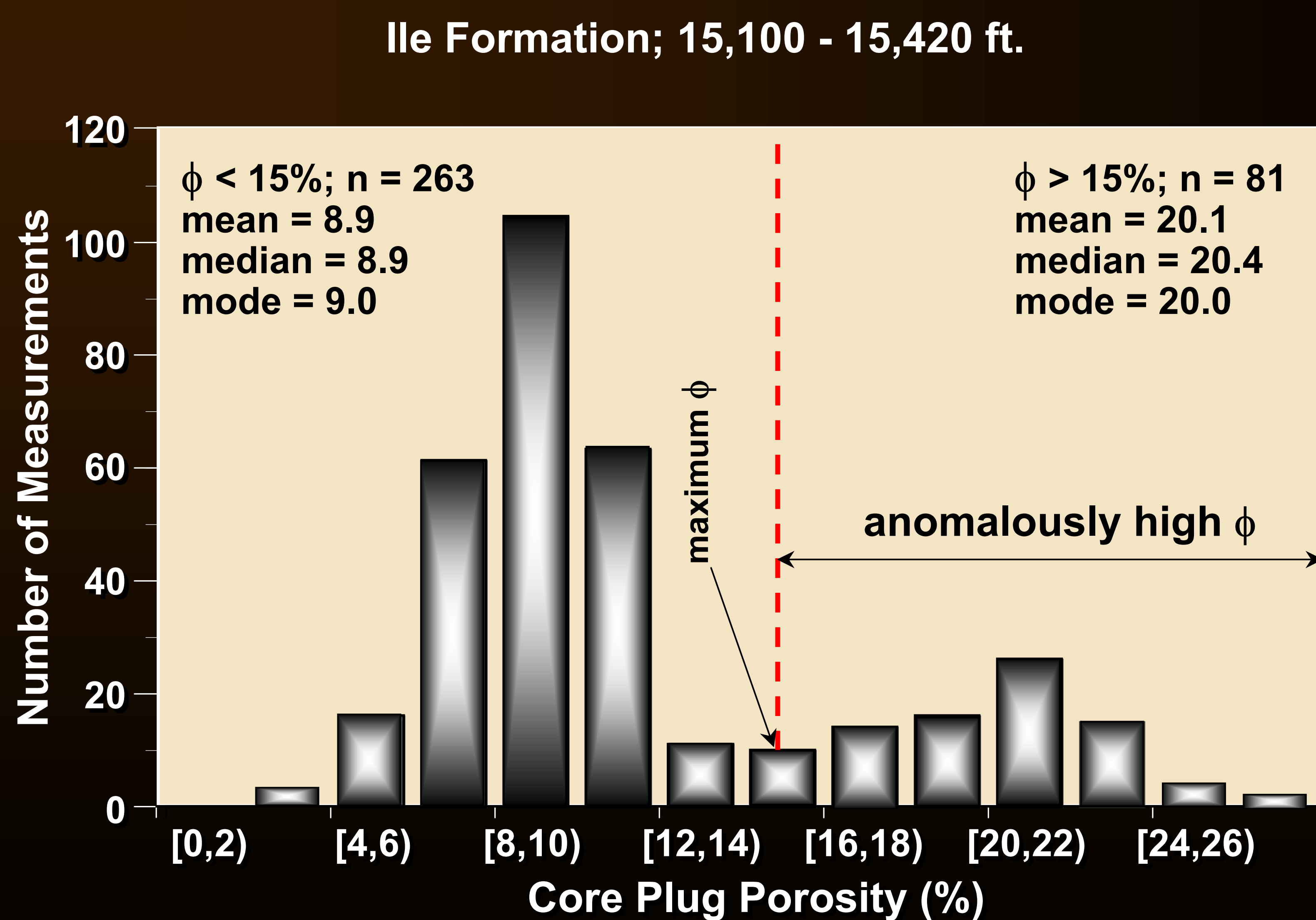
Normal Distribution of Porosity in a Sandstone with a Moderate Diagenetic Imprint



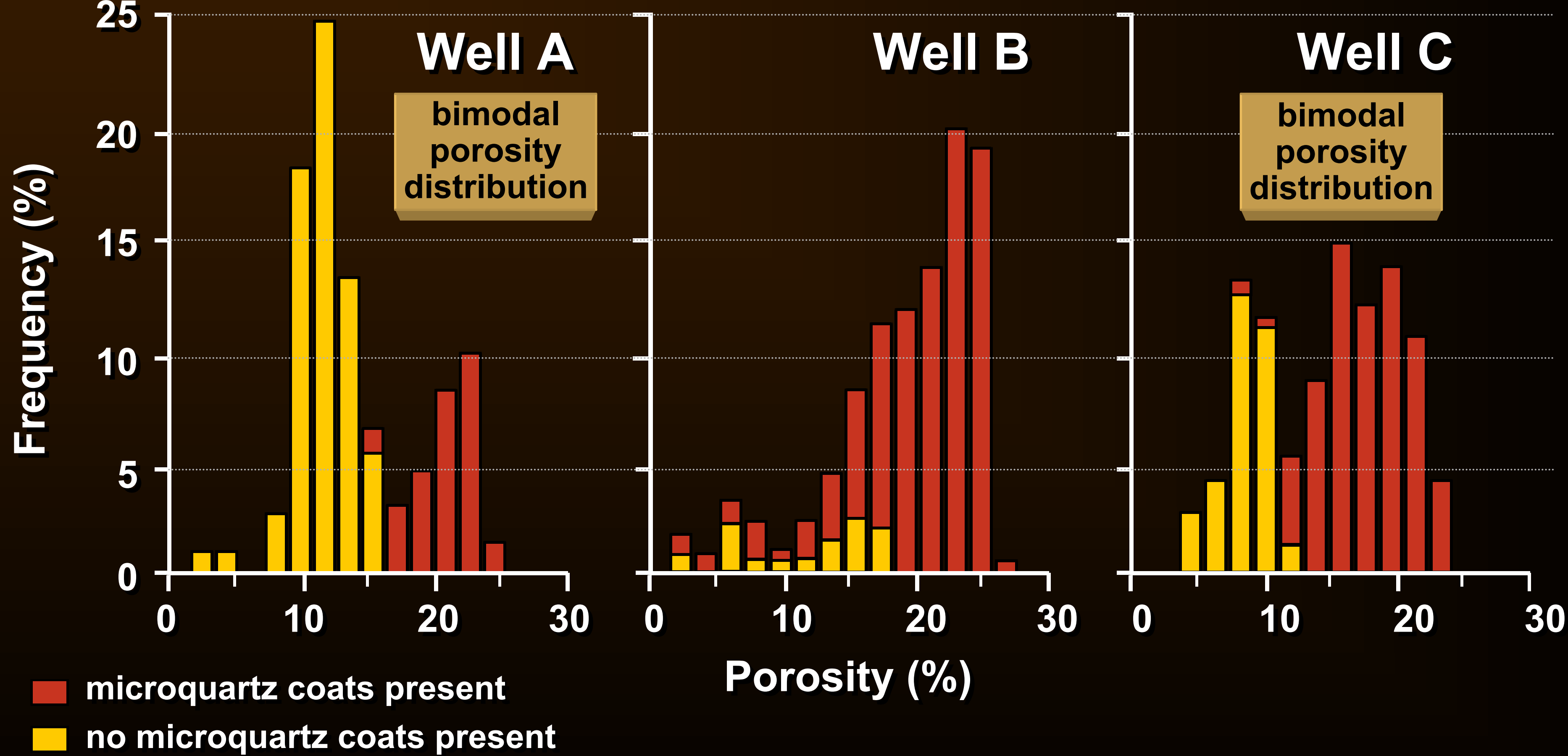
Lognormal Distribution of Porosity in Heavily Cemented Sandstones



Bimodal Distribution of Porosity in Chlorite-Coated Sandstones



Frequency Distribution of Porosity in U. Jurassic Sandstones, Central Graben
(Ula & Gyda Fields), North Sea



from Aase et al., 1996

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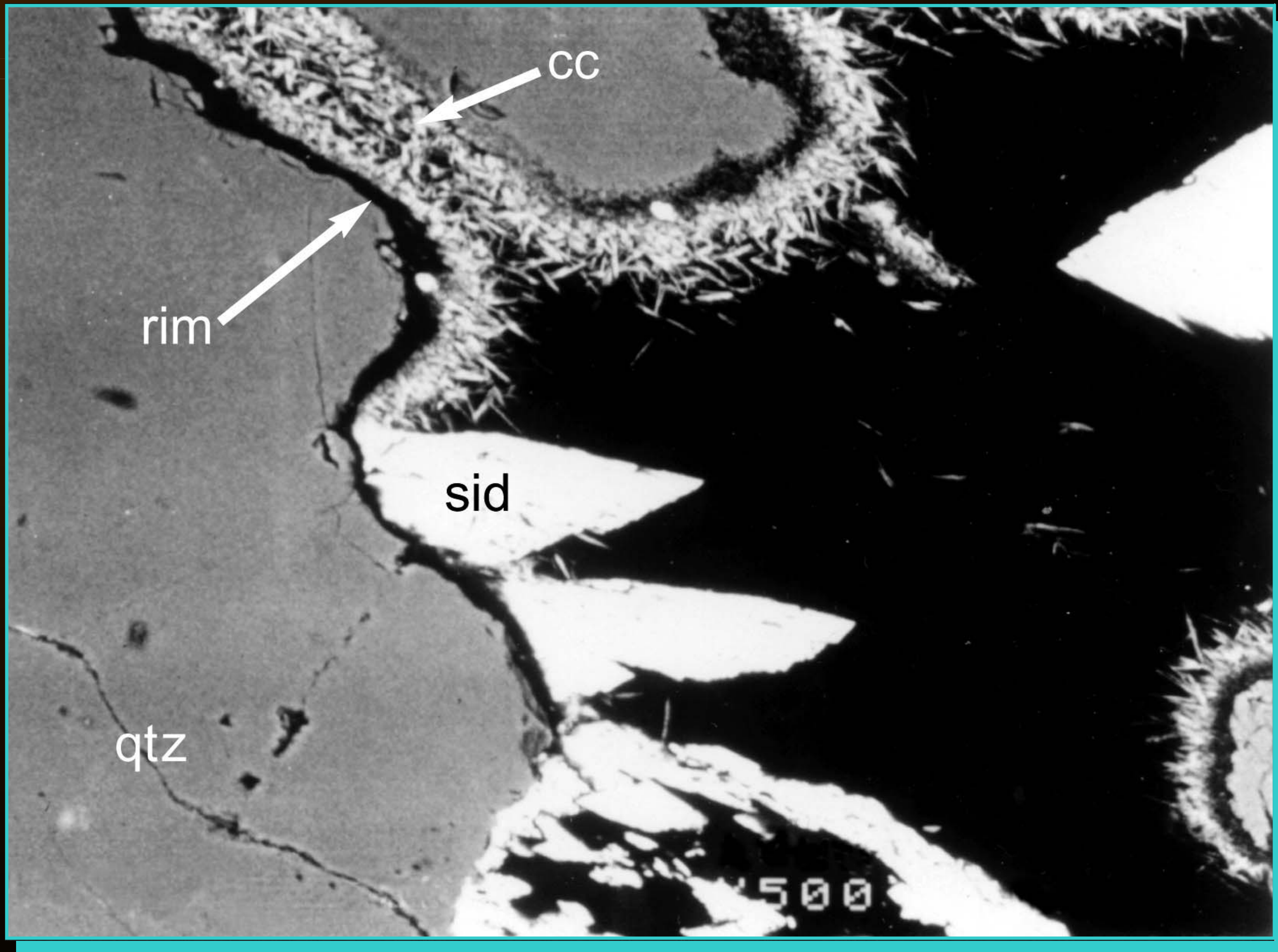
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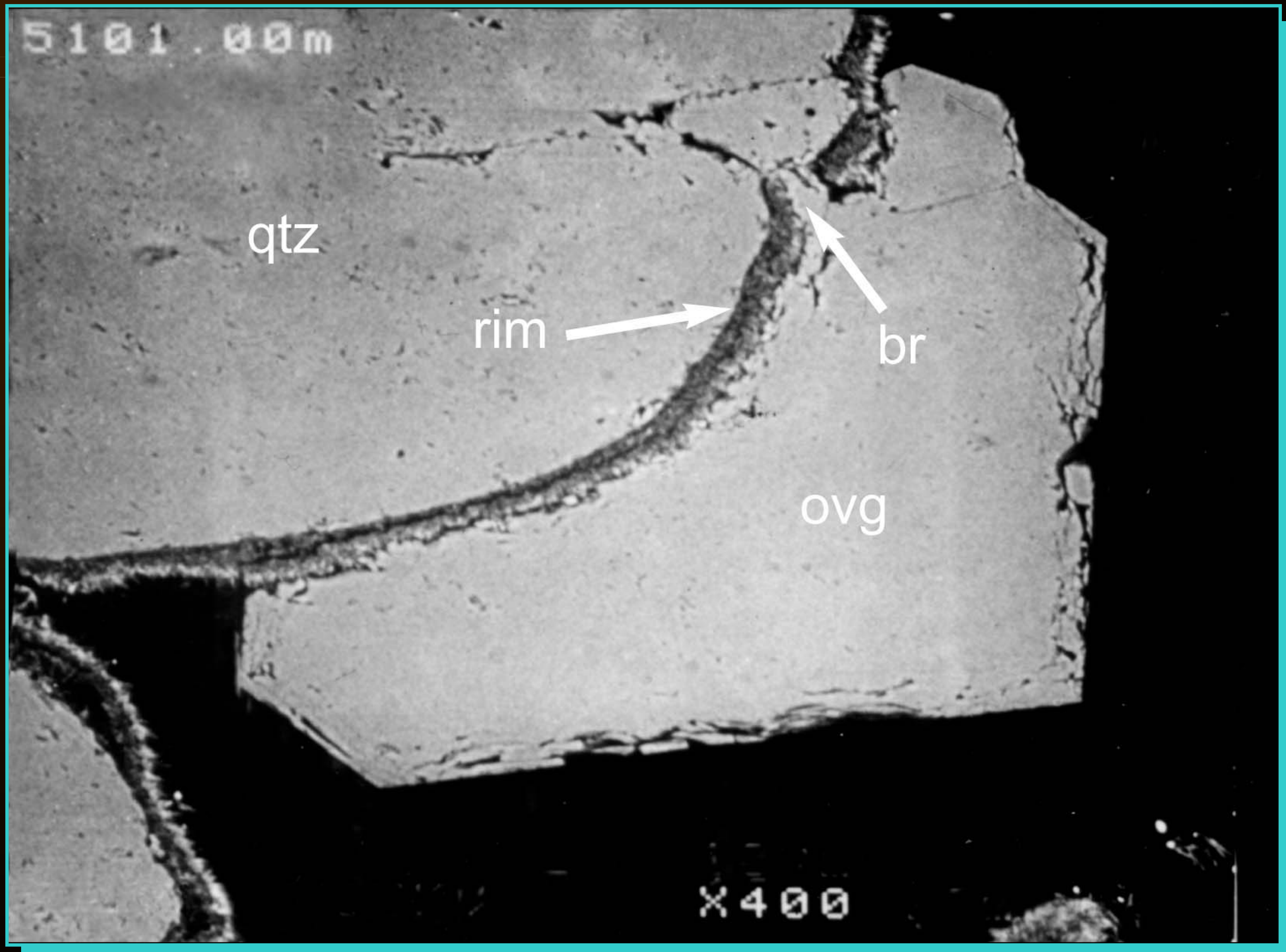
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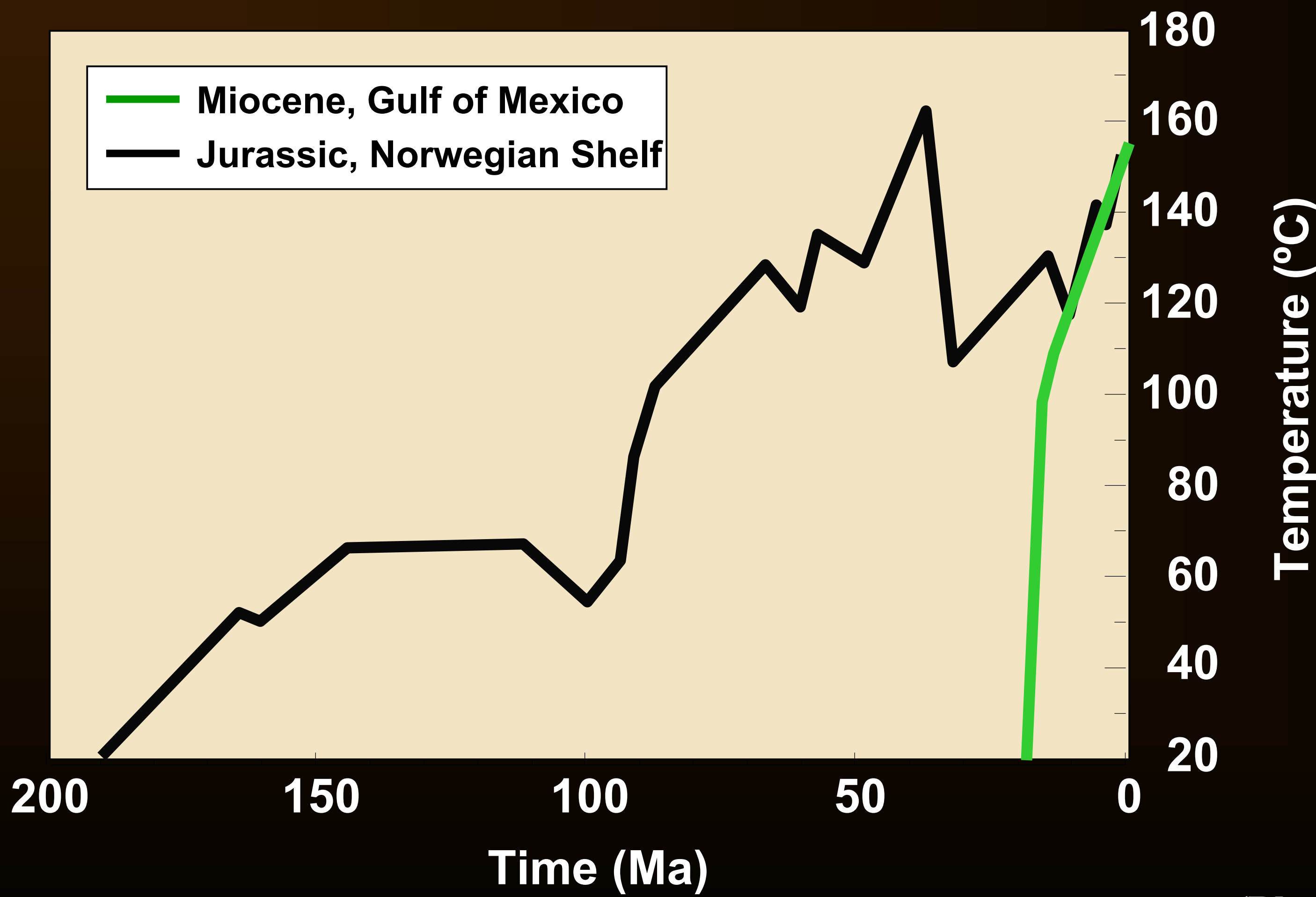
Origin of Chlorite Coats

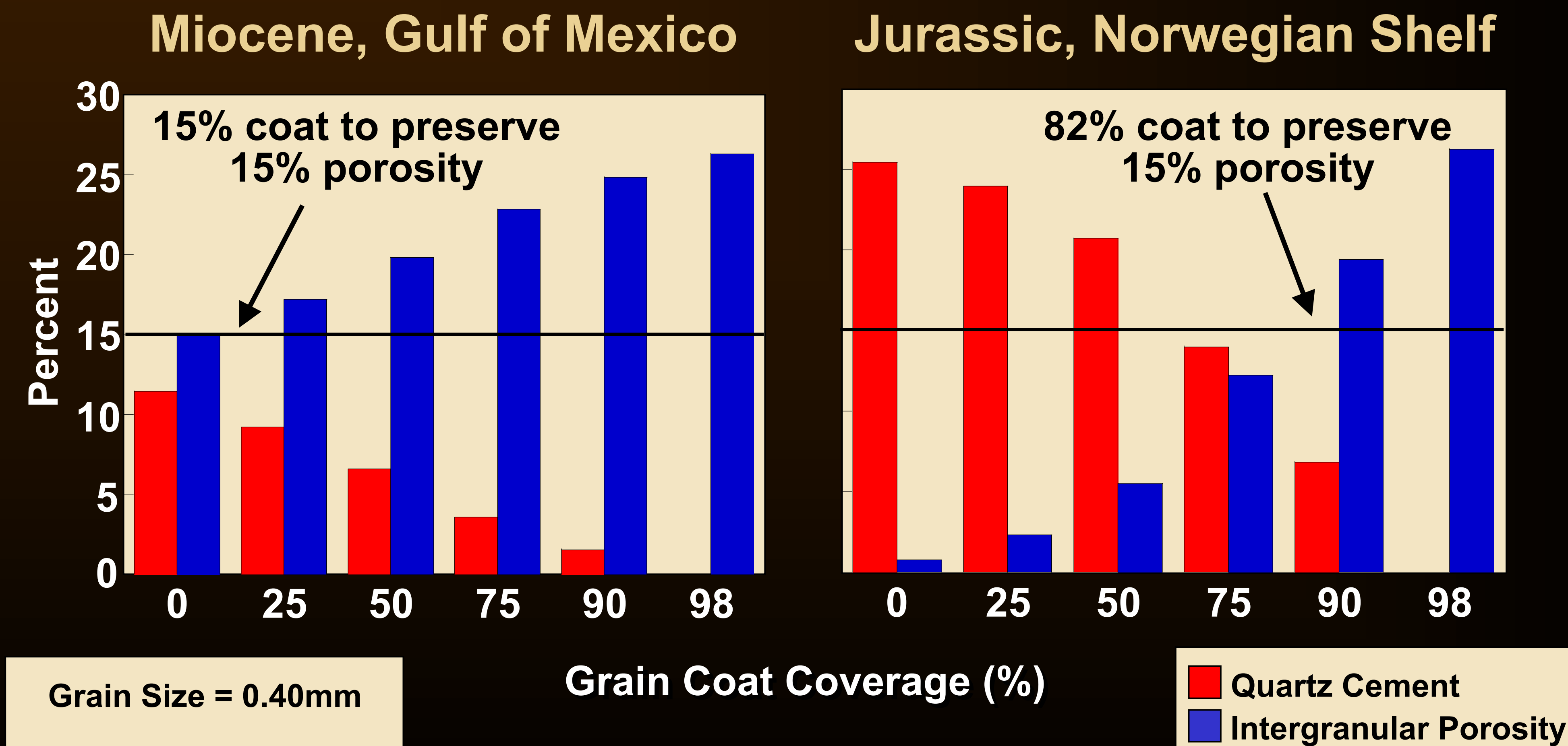
- **depositionally-controlled Fe-rich coats in high-energy, shallow-marine sandstones shelf (*Ehrenberg, 1993)***
- **depositionally-controlled coats in turbidites** *(Houseknecht & Ross, 1991)*
- **down-slope transport of coated shallow-marine sands** *(Sullivan et al., 1999)*
- **provenance-controlled (VRFs) coats** *(Thomson, 1979; Pittman et al., 1992)*
- **Mg-rich coats formed by interaction of precursor clay/iron oxide grain rims with Mg-rich saline brines** *(Kugler & McHugh, 1990)*

Effect of Grain Coating & Burial History on Porosity Preservation - Diagenetic Models



(Bloch et al., 2002)

Effect of Grain Coating & Burial History on Porosity Preservation - Diagenetic Models



(Bloch et al., 2002)

Prediction of p&p Preservation by Chlorite Coats

- the effect of coats on p&p cannot be accurately quantified prior to drilling
- the distribution pattern of coated sands is a function of coat origin
- the potential impact of coats on p&p can be evaluated by diagenetic models

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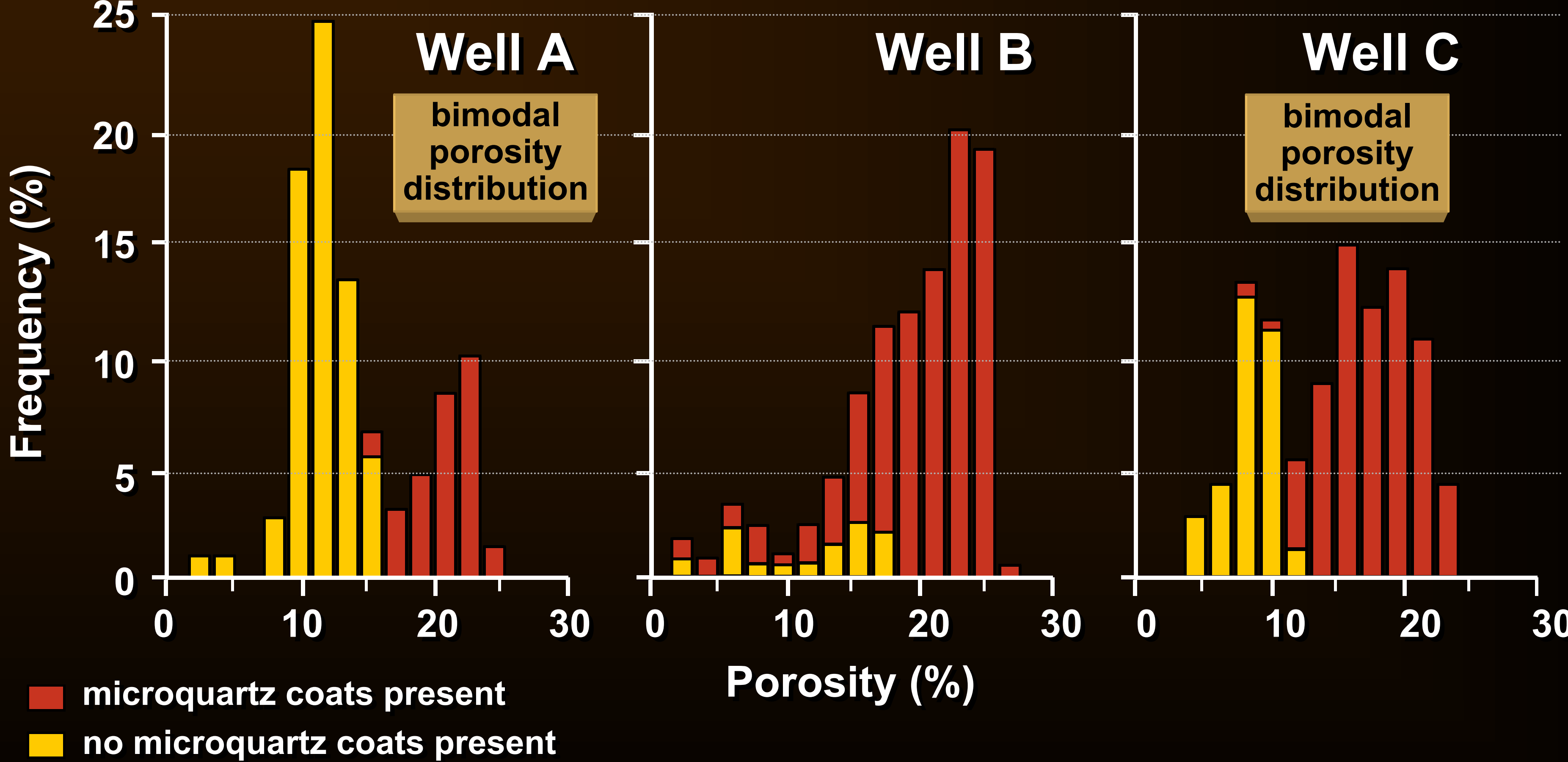

from Aase et al., 1996

Conclusions

- Microquartz Coats
  - Geological Prediction of Anomalous p&p due to Microquartz Coats in Not Possible in Frontier Basins
    - Distribution of sponge spicule-sourced coats - mapping sponge spicule-prone sedimentary facies and their reworking paths into sand-rich depo systems
    - Distribution of coats sourced by dissolution of volcanic glass - occurrence within specific isochronous sandy intervals of the sedimentary column

from Aase et al., 1996

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Effect of HC Emplacement on Preservation of p&p

Pitfalls:

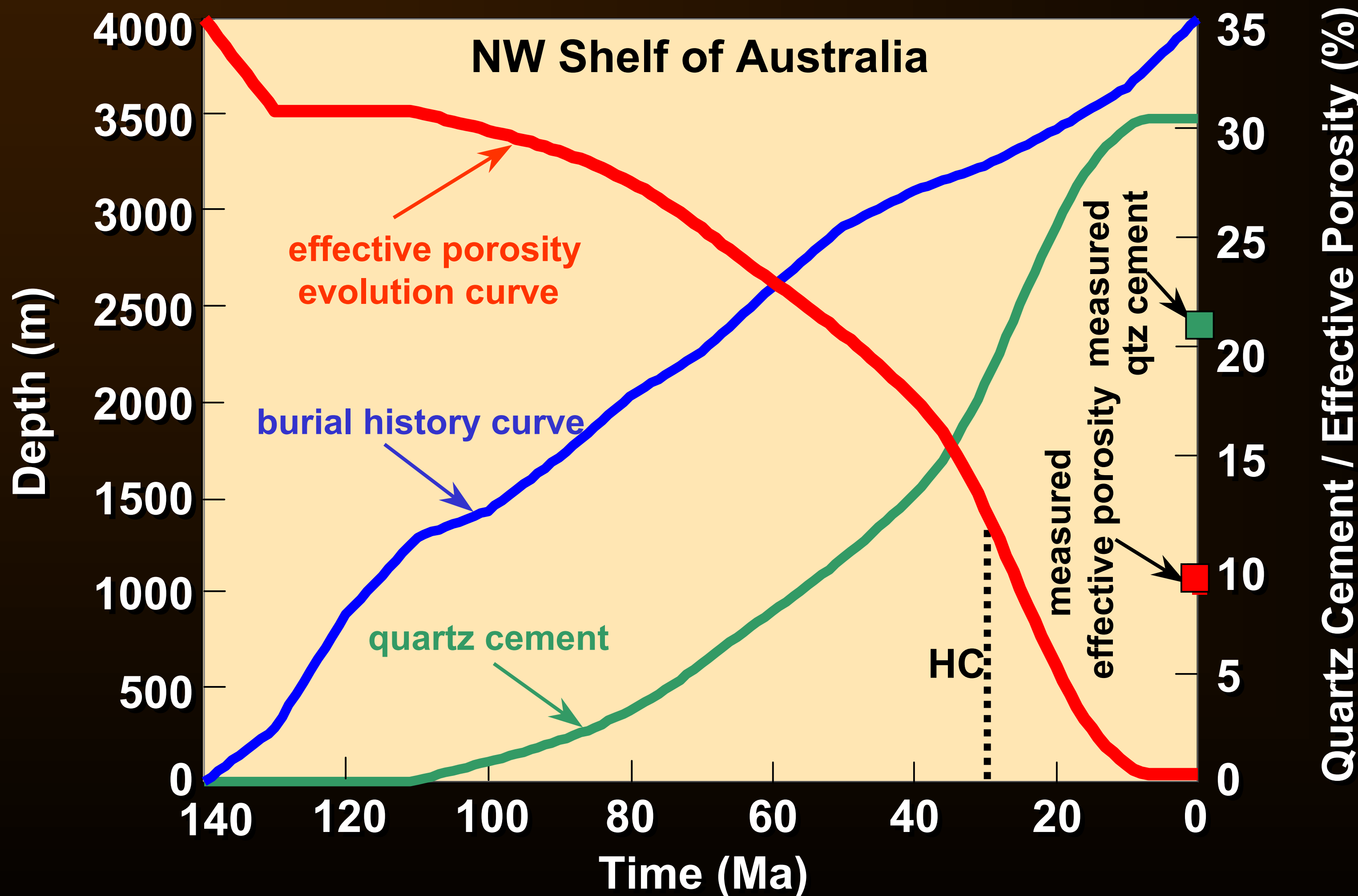
- effect of wettability on cementation
- differences in texture, composition, and thermal exposure in samples from water legs versus hydrocarbon legs
- poor control on hydrocarbon filling and leakage histories

Effect of HC Emplacement on Preservation of p&p

- silica provided externally by advection ("open system") - cementation stopped
- silica supplied internally ("closed system") in water-wet reservoirs - cementation retarded, but not stopped
- silica supplied internally ("closed system") in oil-wet reservoirs - cementation stopped

From Worden et al. (1998)

Mid-Tertiary Hydrocarbon Emplacement Preserved 9% of Effective Porosity



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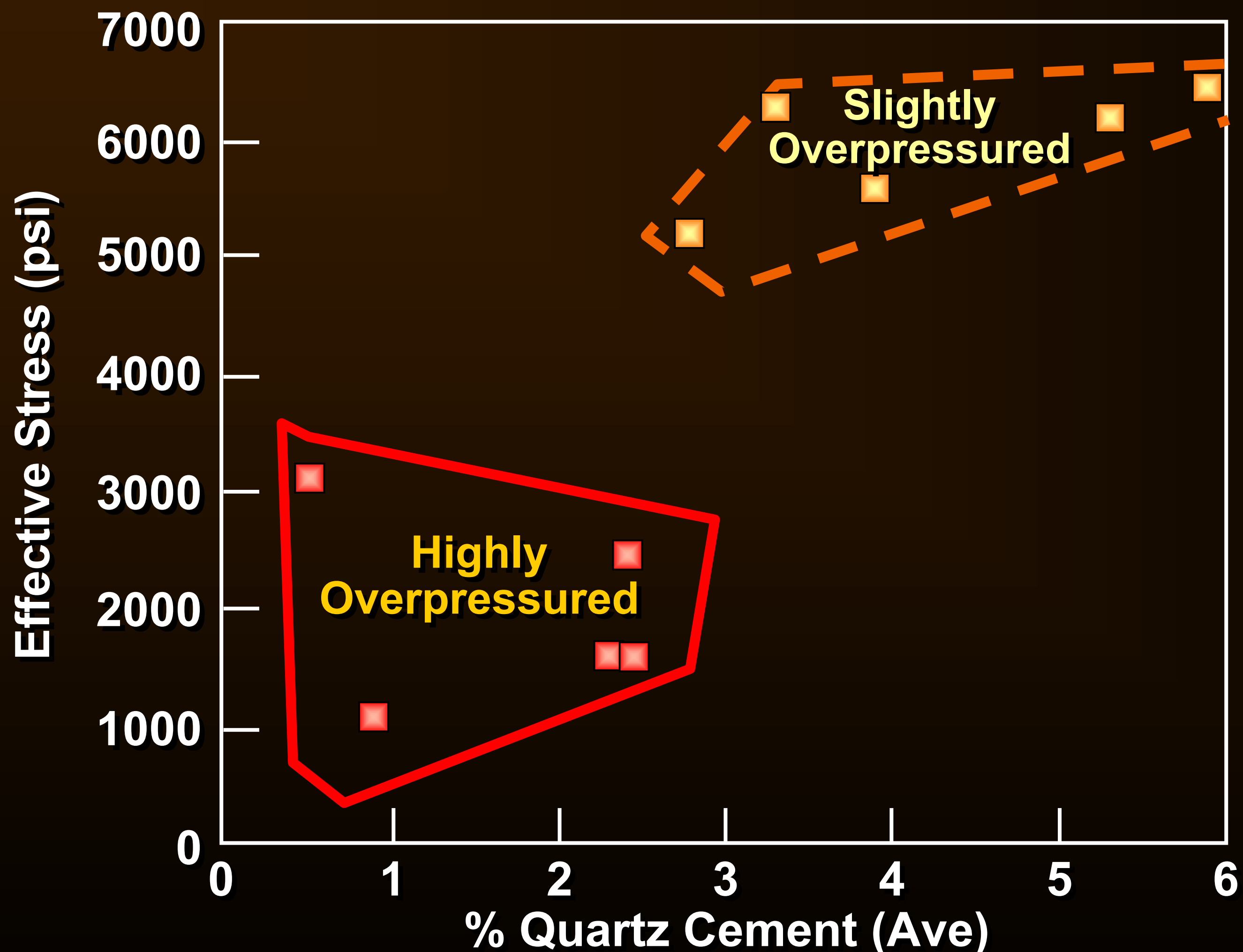
Effect of Overpressure on Porosity Preservation: Model Assumptions

- Compaction and quartz cementation are the primary controls on reservoir quality
- Linear burial to 4000 m at 30 ºC/km
- Present-day overpressure near fracture gradient
  - "Shallow" scenario: develops 0 - 800 m
  - "Deep" scenario: develops 2400 - 4000 m
- Sandstones are medium grained, well sorted, and "clean"
- Composition of sandstones:
  - "Quartzose": $Q_{84}F_8L_8$
  - "Lithic": Q_{50} F_0L_{50} (L = shale clasts)

Quartz Cement Abundance Vs. Effective Stress at 3.5 - 6.0 km, North Sea HPHT Clastic Reservoirs



from Osborne & Swarbrick, 1999

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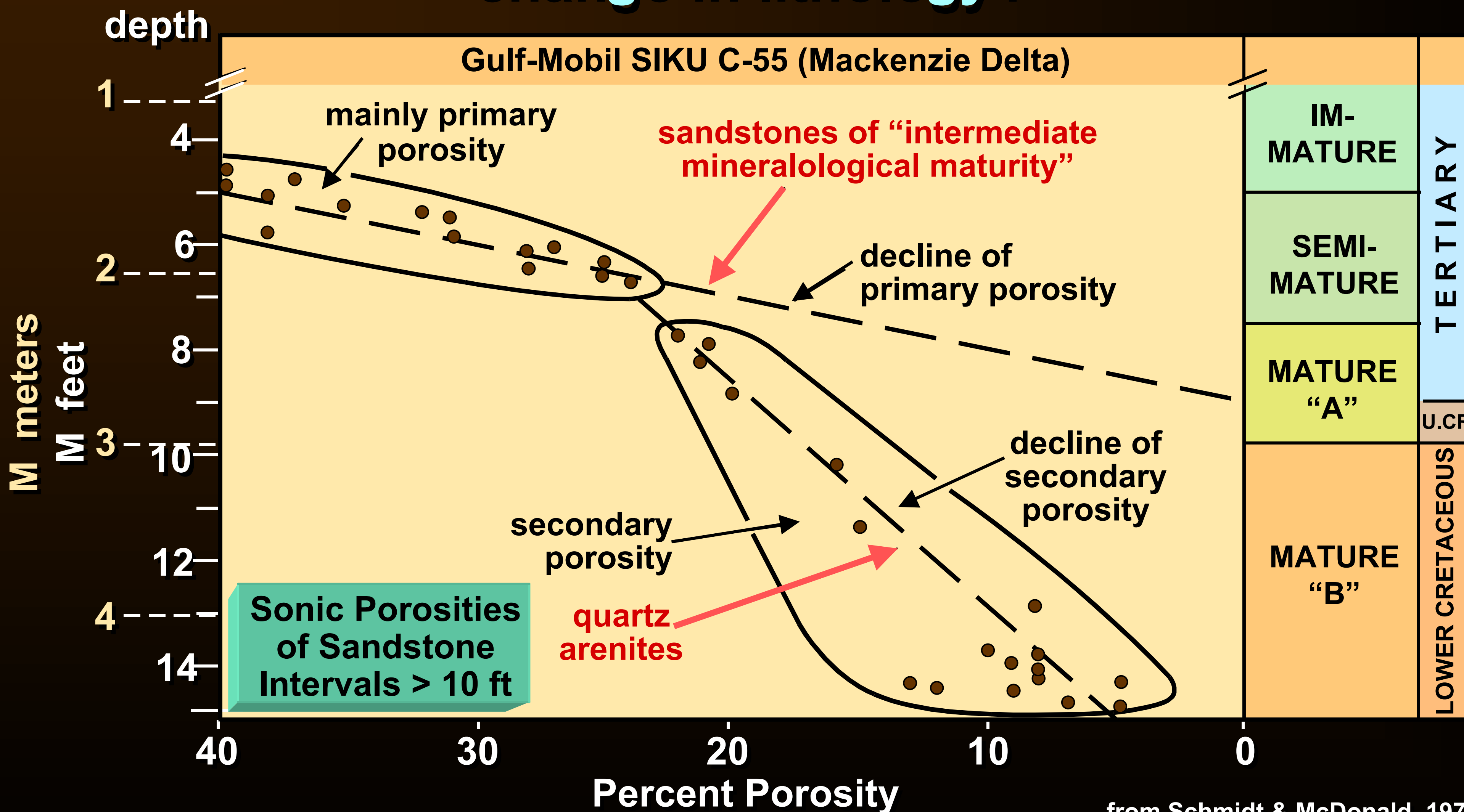
Is the change in porosity gradient due to secondary porosity or provenance/facies-controlled change in lithology?



from Schmidt & McDonald, 1978

Plagioclase Dissolution Porosity

Conclusions

- much of the plagioclase dissolution porosity (PDP) at depths >5000 ft may be inherited shallow PDP
- if deep PDP is mostly inherited, there may be no aluminum problem
- the presence of PDP does not have a major impact on the accuracy of empirical predrill predictions of porosity in sandstones

The Dataset

216 Middle Eocene - Lower Miocene arkosic sandstone samples from 16 wells in southern San Joaquin basin *(Metralla, San Emigdio, Vedder, and Jewett)*

depth range: 2480 ft - 14,710 ft

similar composition

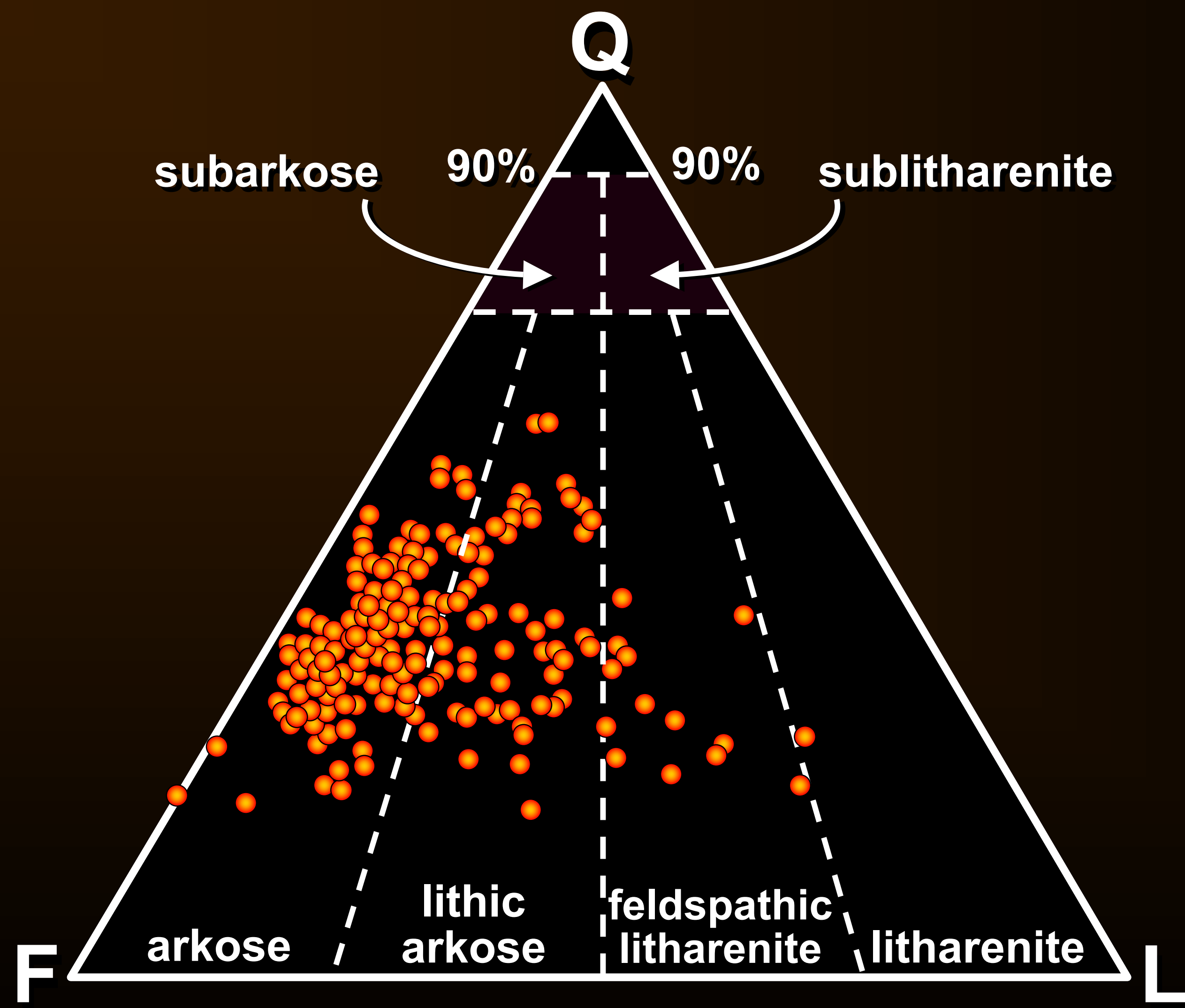
secondary porosity formed predominately by dissolution of plagioclase

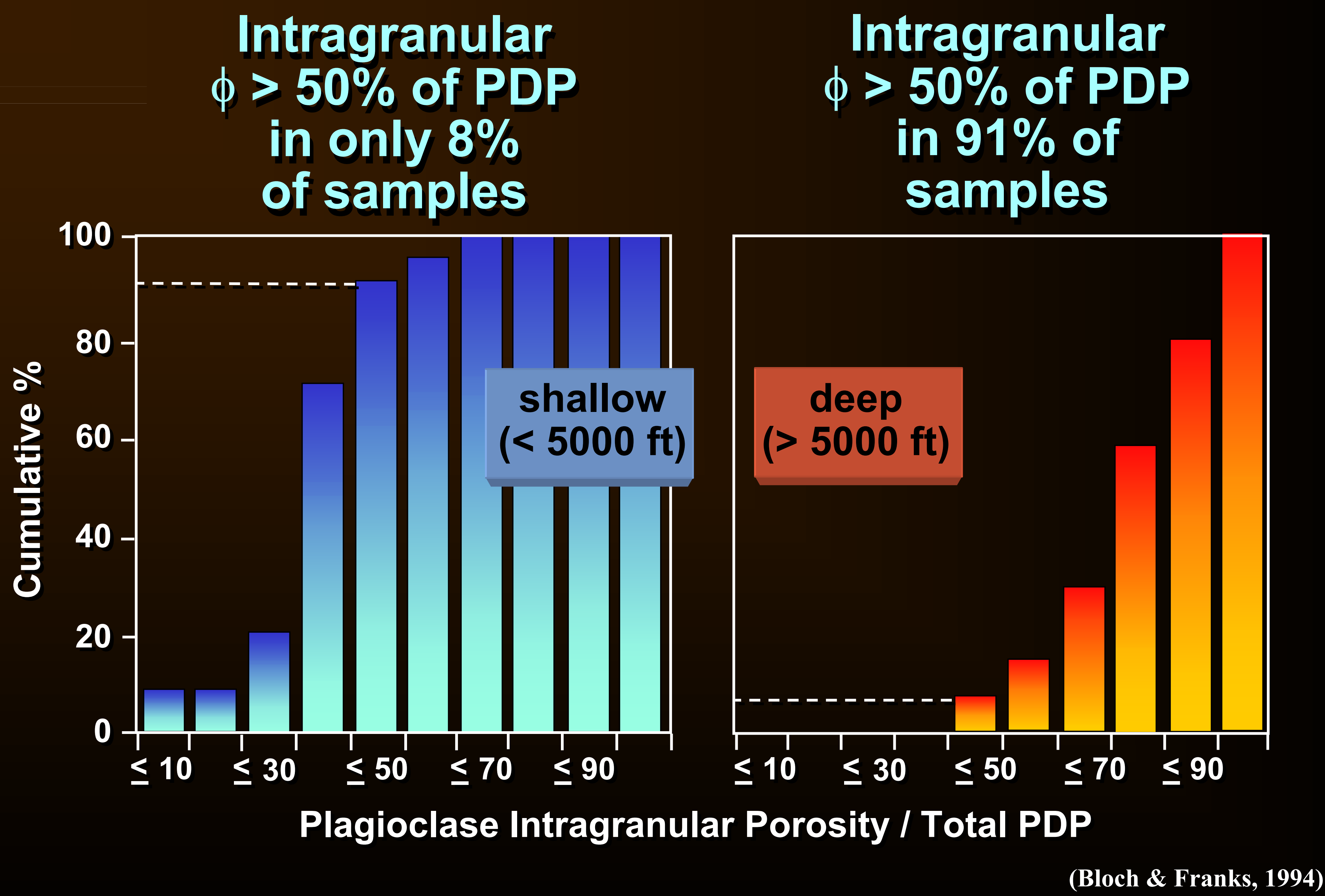
300 counts per thin-section
1000 counts on subset of 39 thin-sections

Reliability of Point-Count Data

- **subjectivity of point-counting secondary porosity**
  (primary vs. secondary, intragranular vs. moldic)
- **errors implicit in point counting**
  (accuracy is a function of true abundance of pores and the number of point counts)

QFL Diagram of Feldspathic Sandstones, Southern San Joaquin Basin, California




Intragranular
ϕ > 50% of PDP
in only 8%
of samples
Intragranular
ϕ > 50% of PDP
in 91% of
samples
100
80
60
40
20
0
Cumulative %
shallow
(< 5000 ft)
deep
(> 5000 ft)
≤ 10
≤ 30
≤ 50
≤ 70
≤ 90
≤ 10
≤ 30
≤ 50
≤ 70
≤ 90
Plagioclase Intragranular Porosity / Total PDP
(Bloch & Franks, 1994)

Conclusions

- Moldic porosity dominates PDP in shallow sandstones (<5000 ft)
- Intergranular porosity dominates PDP in deeper sandstones (>5000 ft)

Proposed Mechanism for PDP Formation

< 5000 feet

mostly moldic PDP generated

- precipitation of some kaolinite
- Al is mobilized beyond thin-section scale

> 5000 feet

mostly intragranular PDP generated

- shielding of some shallow moldic PDP by rigid grain framework + cement
- collapse of some shallow moldic PDP
- precipitation of authigenic clays; redistributional secondary porosity

Generation of PDP in the Subsurface - Approximate Balance Calculations

Burial	Average Primary Porosity (% v/v)	Relative Loss (%)	Average Plagioclase Intragranular Secondary Porosity	Balance	Average Plagioclase Intragranular Secondary Porosity	Balance
Shallow (< 5,000 ft)	16.2		3.1		1.8	
Deep (> 5,000 ft)	4.4	73	0.5	73% loss gives 0.8%; no gain in moldic porosity	1.5	73% loss gives 0.4%; gain of 1.1% (maximum)

(Bloch & Franks, 1994)

Evolution of Plagioclase Dissolution Porosity

Depth (T, P)

Surface and shallow subsurface dissolution

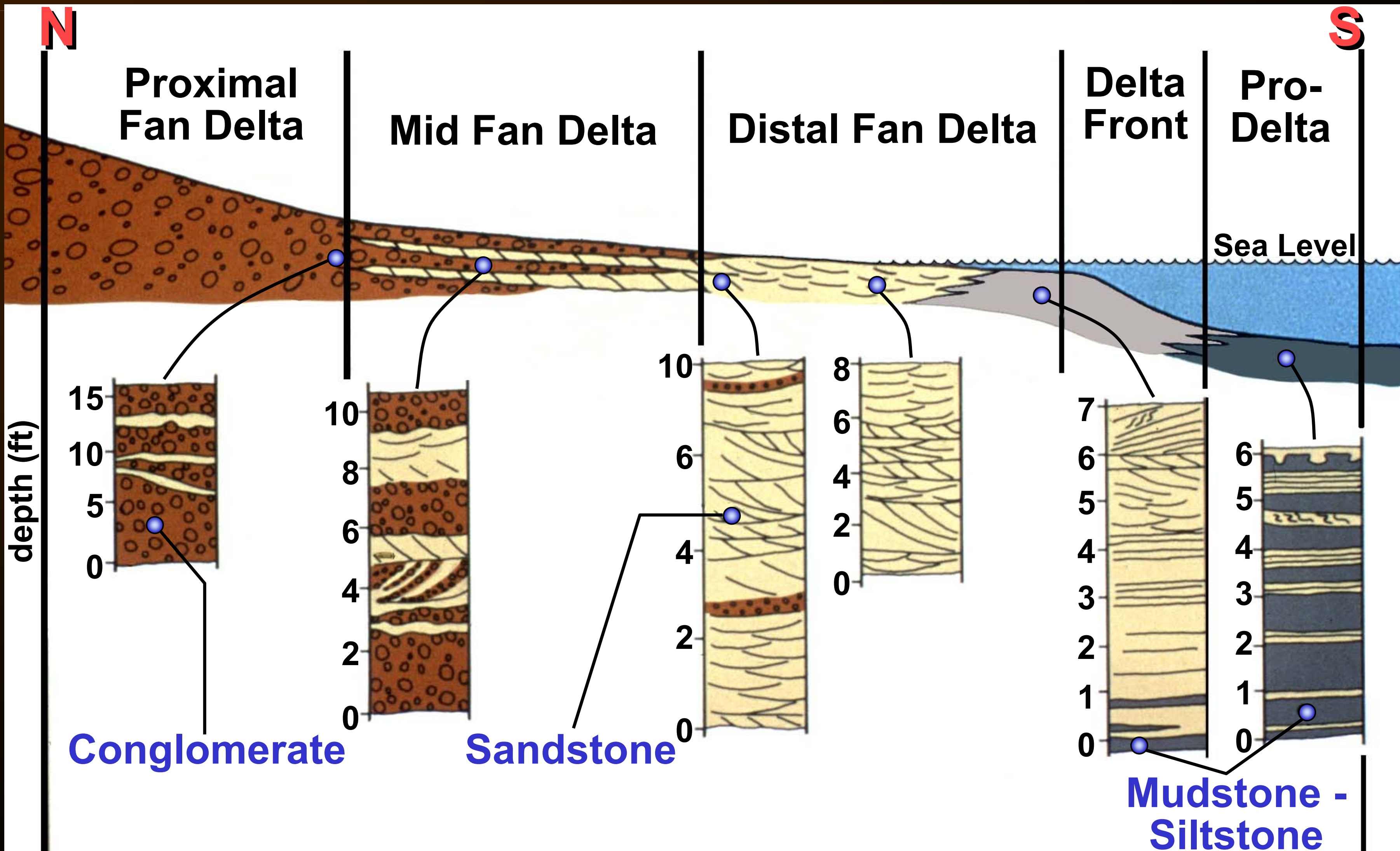
- Major dissolution
- Net porosity gain likely
- Meteoric water

Gradual collapse of primary and moldic porosity

Deep dissolution

- Minor dissolution
- "Redistributional" secondary porosity
- Silicate hydrolysis (?), organic acids (?)

Fan Delta Model, Cross-Section



from McGowen & Bloch, 1985

Depositional Facies Control of Porosity and Permeability, Prudhoe Bay Field

FACIES	WELL 17-1		COMMENTS
	$\bar{k}$ (md)	$\bar{\phi}$ (%)	
MID FAN DELTA	639	22.5	No Conglomerate
LOWER MID FAN DELTA	512	18.9	16 Conglomerate Samples $\bar{k}$ = 359md 19 Sandstone Samples $\bar{k}$ = 640md
UPPER DISTAL FAN DELTA	685	25.2	No Conglomerate
DISTAL FAN DELTA	349	22.6	
DELTA FRONT	13	14.9	13 Samples Coarser than Fine $\bar{k}$ = 33md 30 Samples Fine and Less $\bar{k}$ = 7md
PRODELTA	NR	NR	

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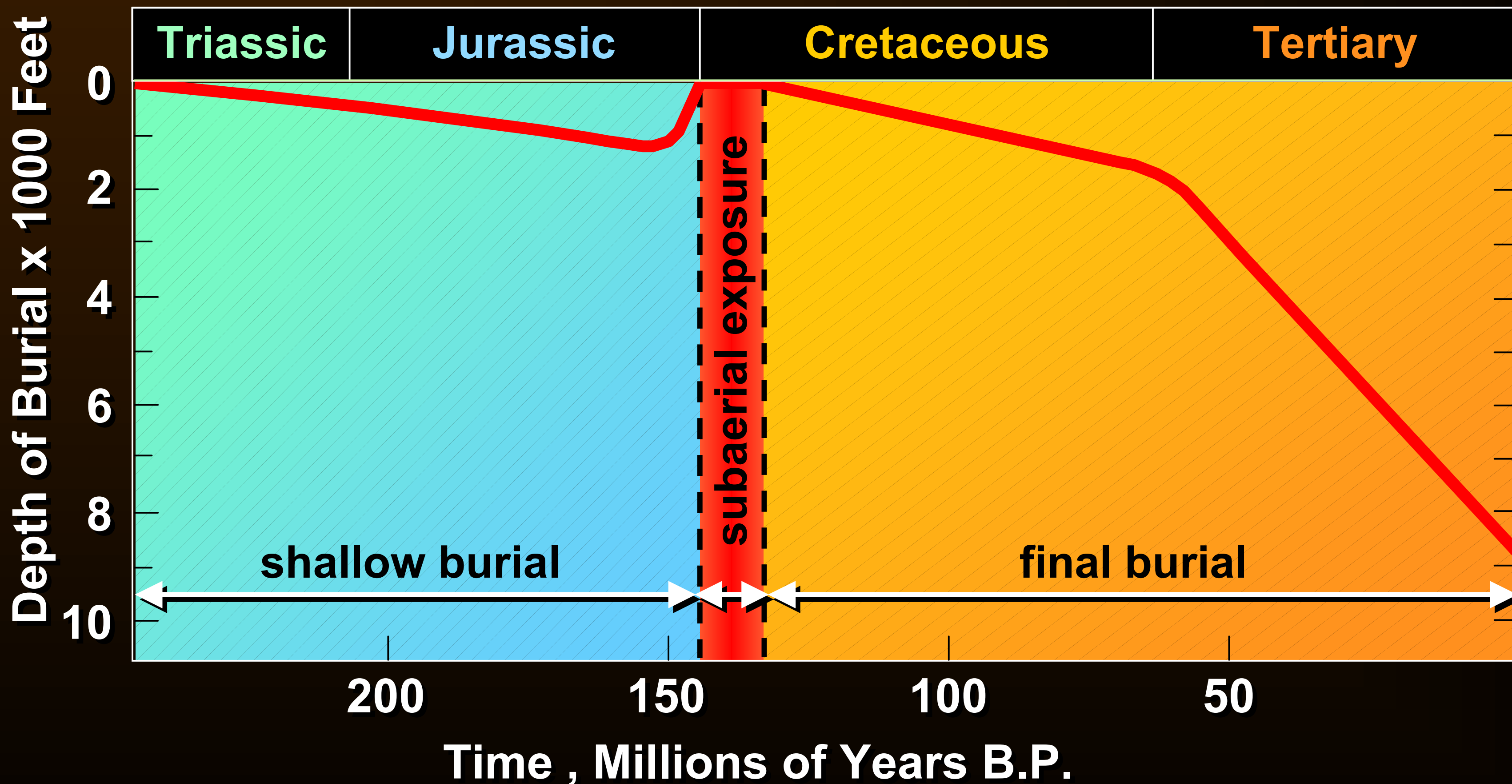
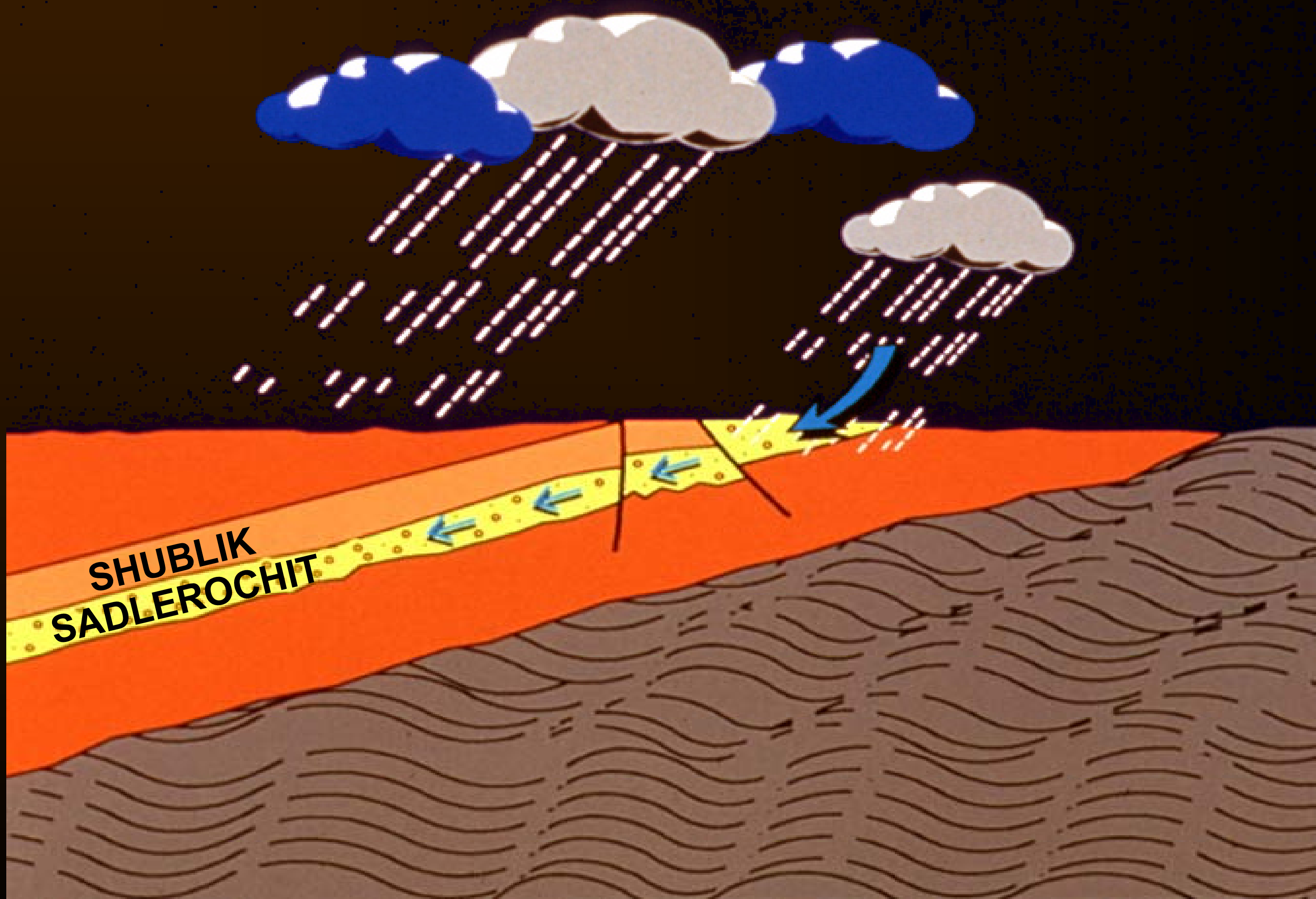
Generalized Burial History of Ivishak Sandstone, Prudhoe Bay Area



(from Shanmugam & Higgins, 1988)

Generation of Secondary Porosity during Subaerial Exposure



Unconformities and Secondary Porosity

Ivishak ss - Prudhoe Bay (N. Slope of Alaska)

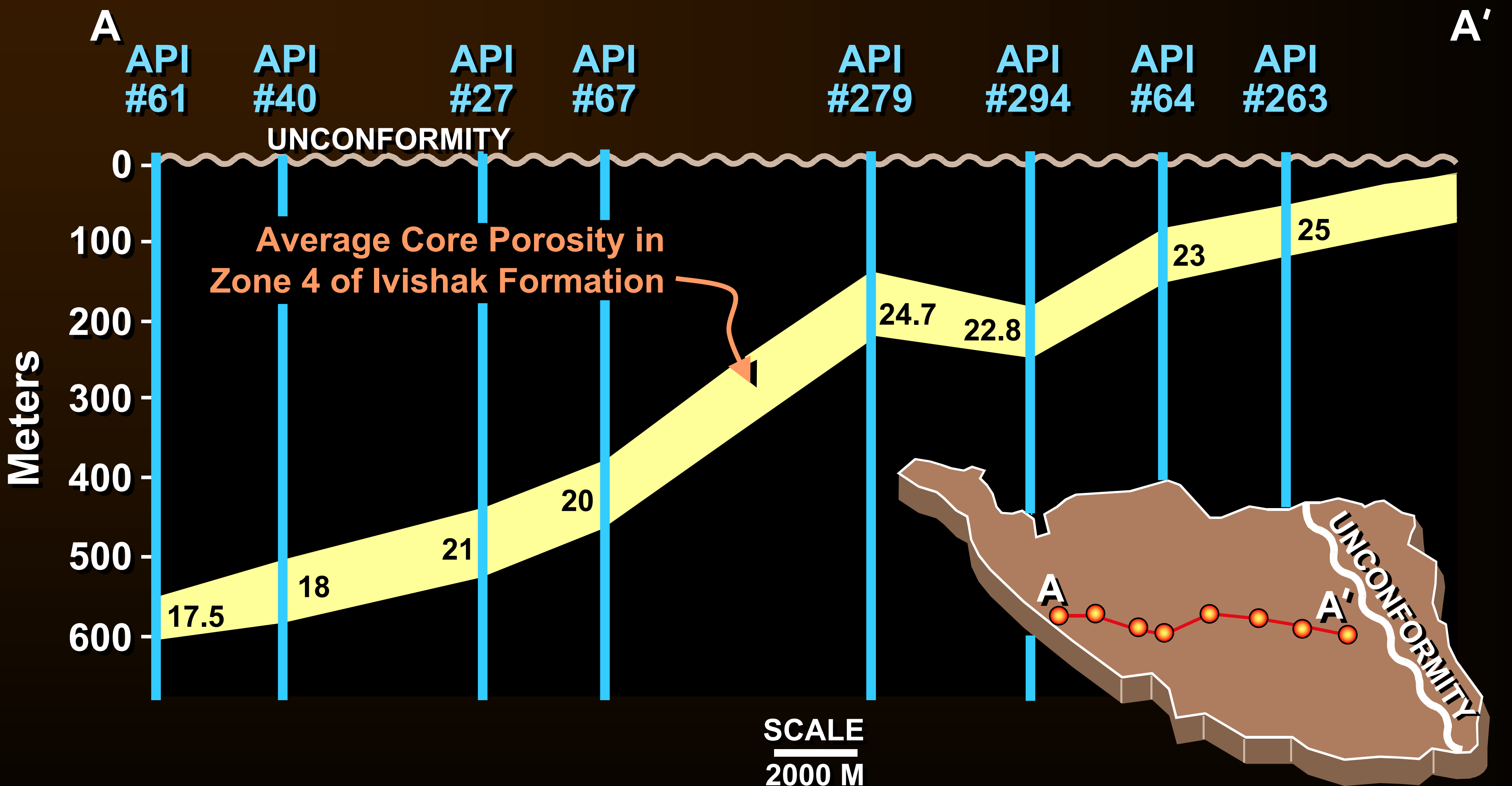
- favorable reservoir quality of *zone 4* of the Ivishak sandstone due to secondary porosity formed by meteoric water leaching of chert beneath the Neocomian unconformity

- macroporosity formed by chert dissolution "tends to increase toward the Neocomian unconformity"

- "a lateral increase in core porosity (from 15% at about 30 km from the unconformity to 30% near the unconformity) and in permeability (from 50 md at about 30 km from the unconformity to 800 md near the unconformity). This increase occurs within the fluvial facies *(zone 4)* of nearly uniform grain size and framework composition (chert litharenite)"

(from Shanmugam & Higgins, 1988)

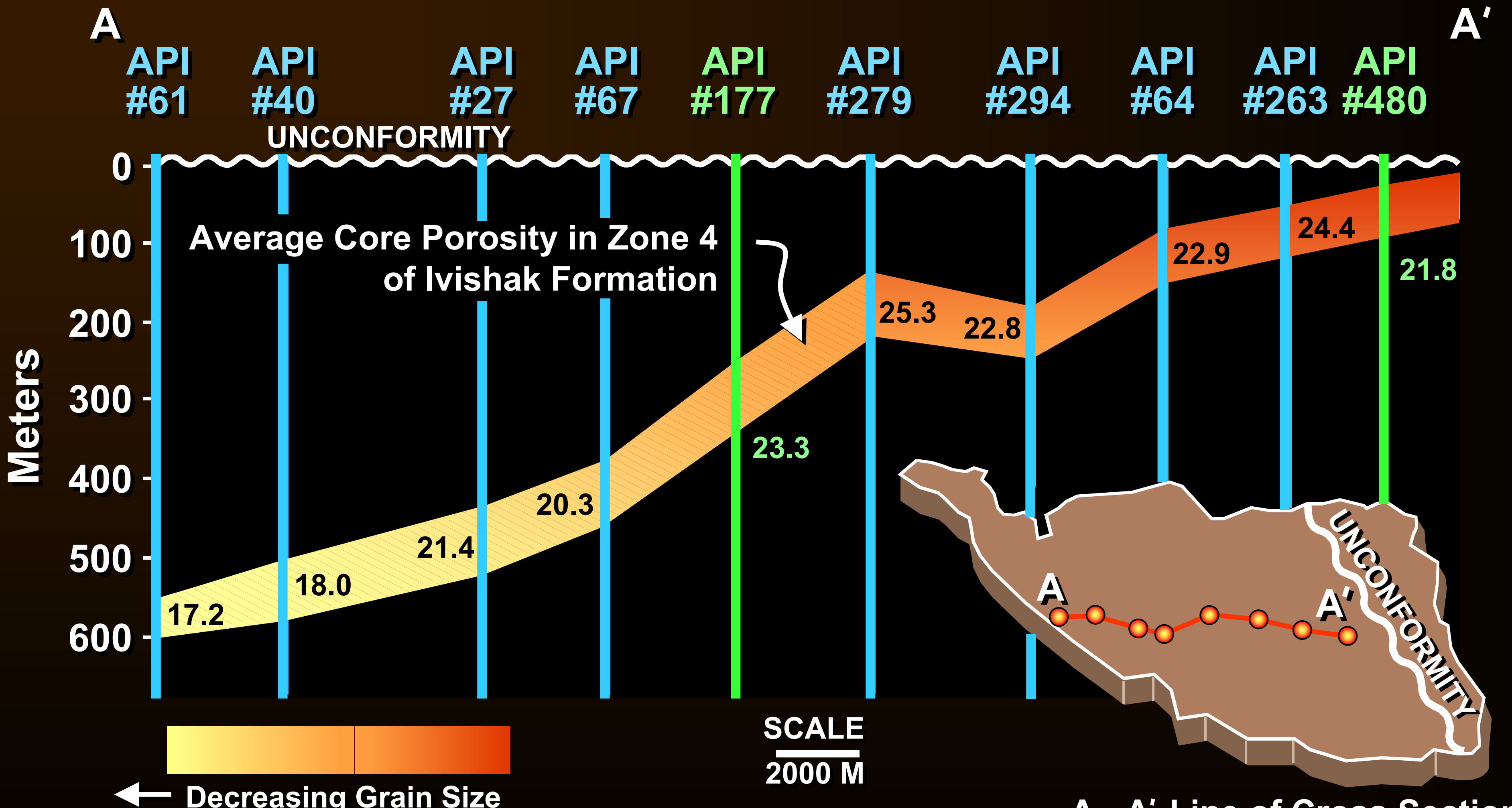
Cross Section is Interpreted to Show Porosity Increase with Increasing Proximity to Unconformity



A - A′ Line of Cross Section
Prudhoe Bay Field, Alaska

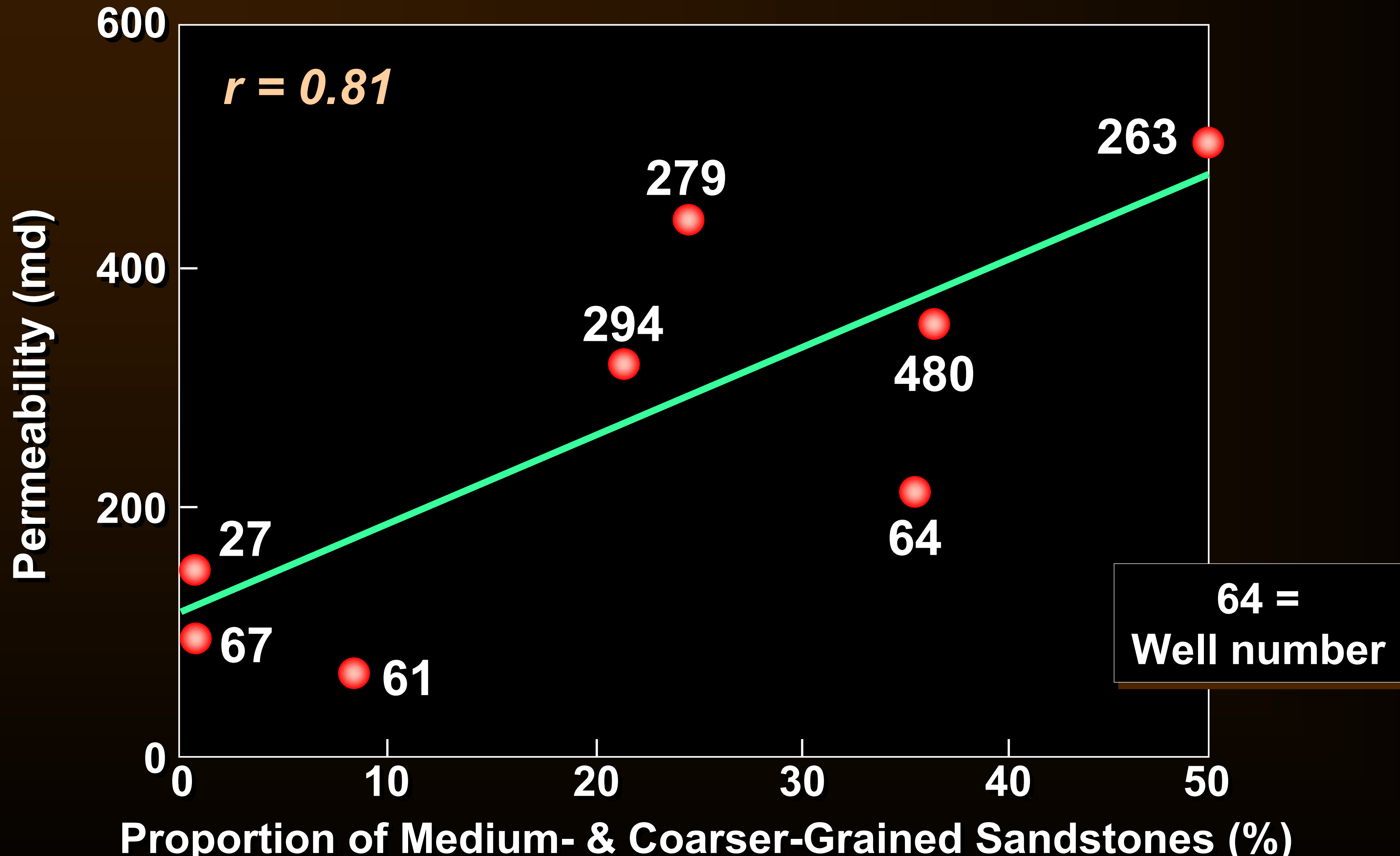
from Shanmugam & Higgins, 1988

There is a "Casual" Correlation between Porosity and Proximity to Unconformity

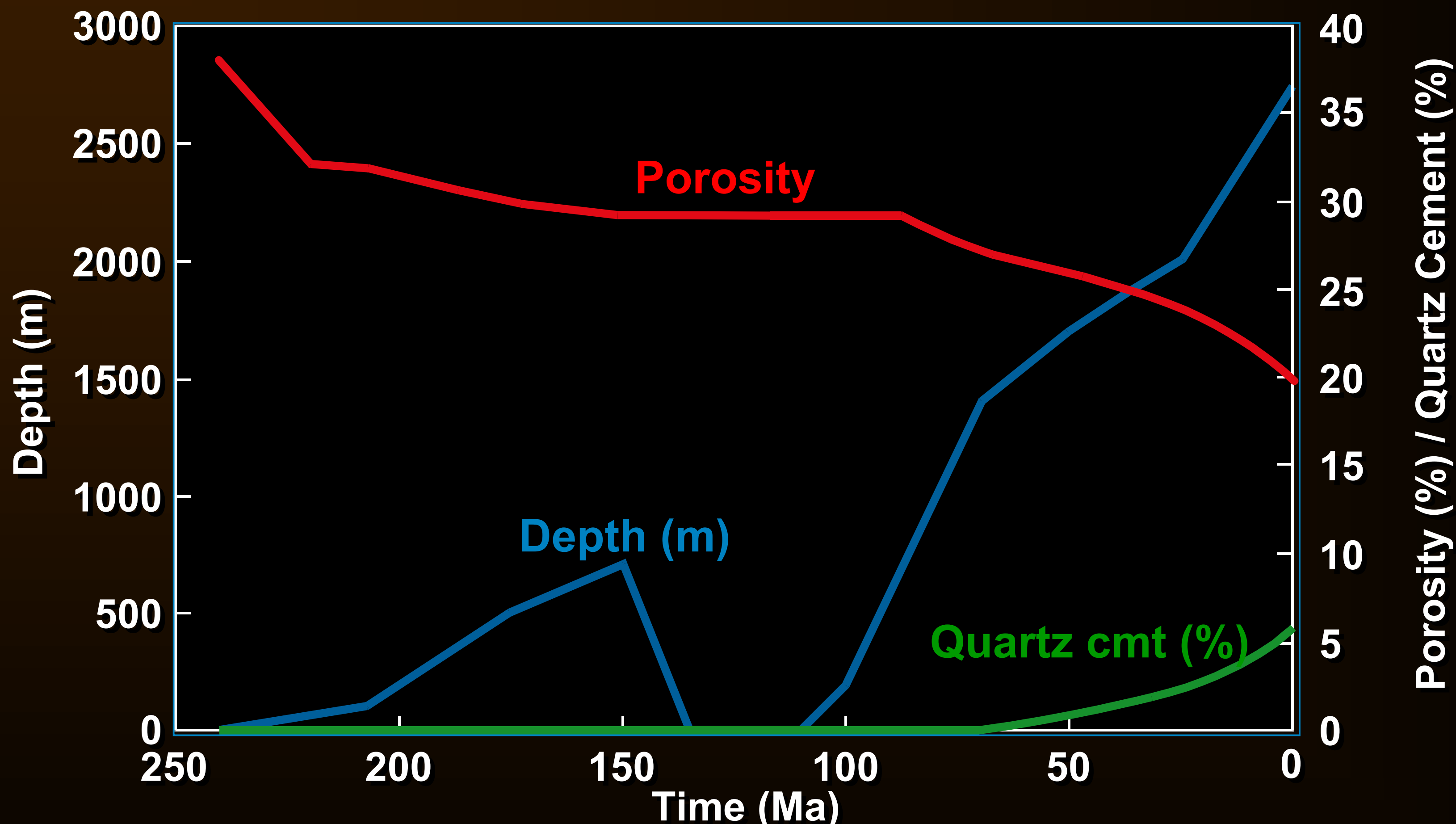


A - A′ Line of Cross Section
Prudhoe Bay Field, Alaska

Average Permeability of the Ivishak Sandstone Correlates Well with Grain Size

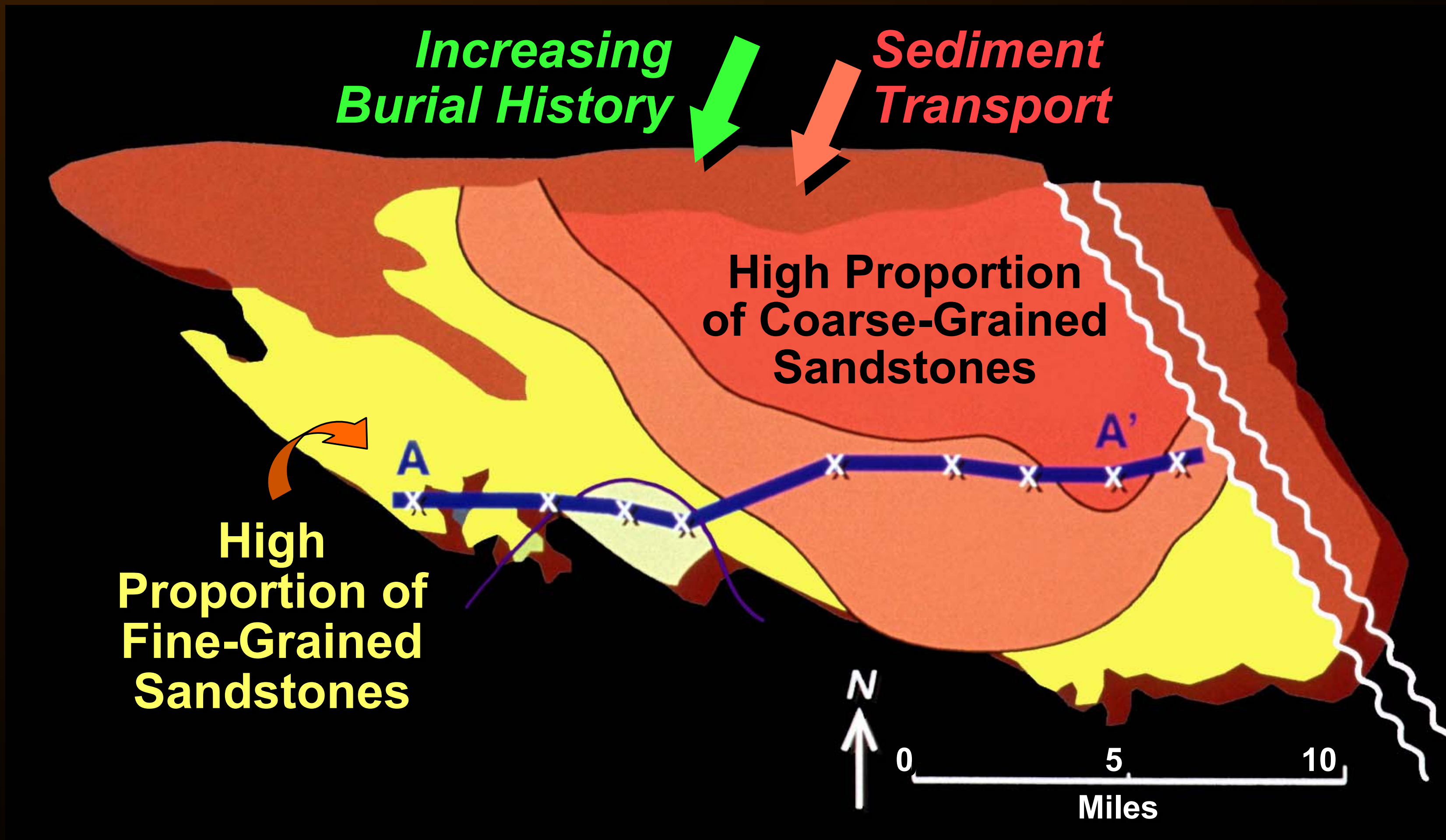


Modeled Porosity Evolution of the Ivishak Sandstone



depth = 9,300 ft; grain size = 0.40mm; mod. well sorted; quartz cement = 6%;
modeled TS ϕ = 20%; est. ambient core ϕ = 23% • In situ ϕ = 22%; in situ *k* = 850md

Reservoir Quality of the Ivishak Sandstone is Controlled by Texture and Burial History



(Bloch et al., 1991)