Influence of Clay on Sorption, Aggregation, and Preservation of Organic Matter

THIRD MSL LANDING SITE WORKSHOP
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Clay enrichment on Earth

In place alternation of parent material

- *Biotic soils*
- *Persistent hydrothermal systems*
- *Fault gouge*

Transported sediment

- *Hemi-pelagic and pelagic marine environments*
- *Lake*
- *Fluvial overbank*
- *Glacial till*
- *Fan-outwash playa*
- *Wind-blown clay dunes (rare)*

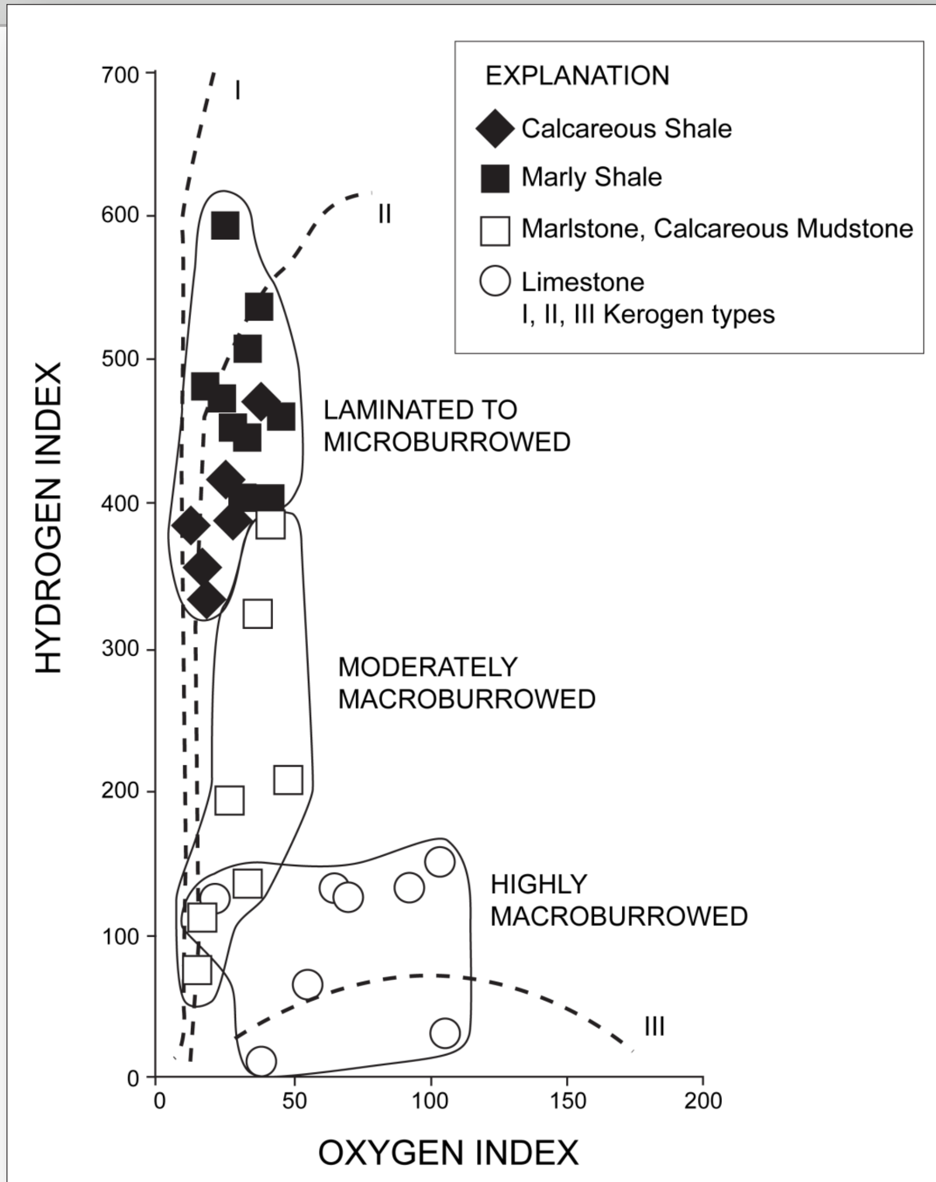
Clay enrichment on Mars

1. *In place alternation of parent rock*
   - *Abiotic soils (? ancient biotic soils)*
   - *Persistent hydrothermal systems*
   - *Fault and impact gouge*

2. *Transported sediment*
   - *Lake*
   - *Glacial till*
   - *Permafrost expulsion (? process)*
   - *Fan-outwash playa*
   - *Wind-blown clay dune (? abundance)*
   - *Wind-blown fine dust (? composition)*

Al Fischer lecturing on the origin of limestone-shale bedding couplets in Cretaceous strata.

Bedding periodicities in this section at Pueblo, Colorado are dominated by the obliquity cycle at about 41 ky.

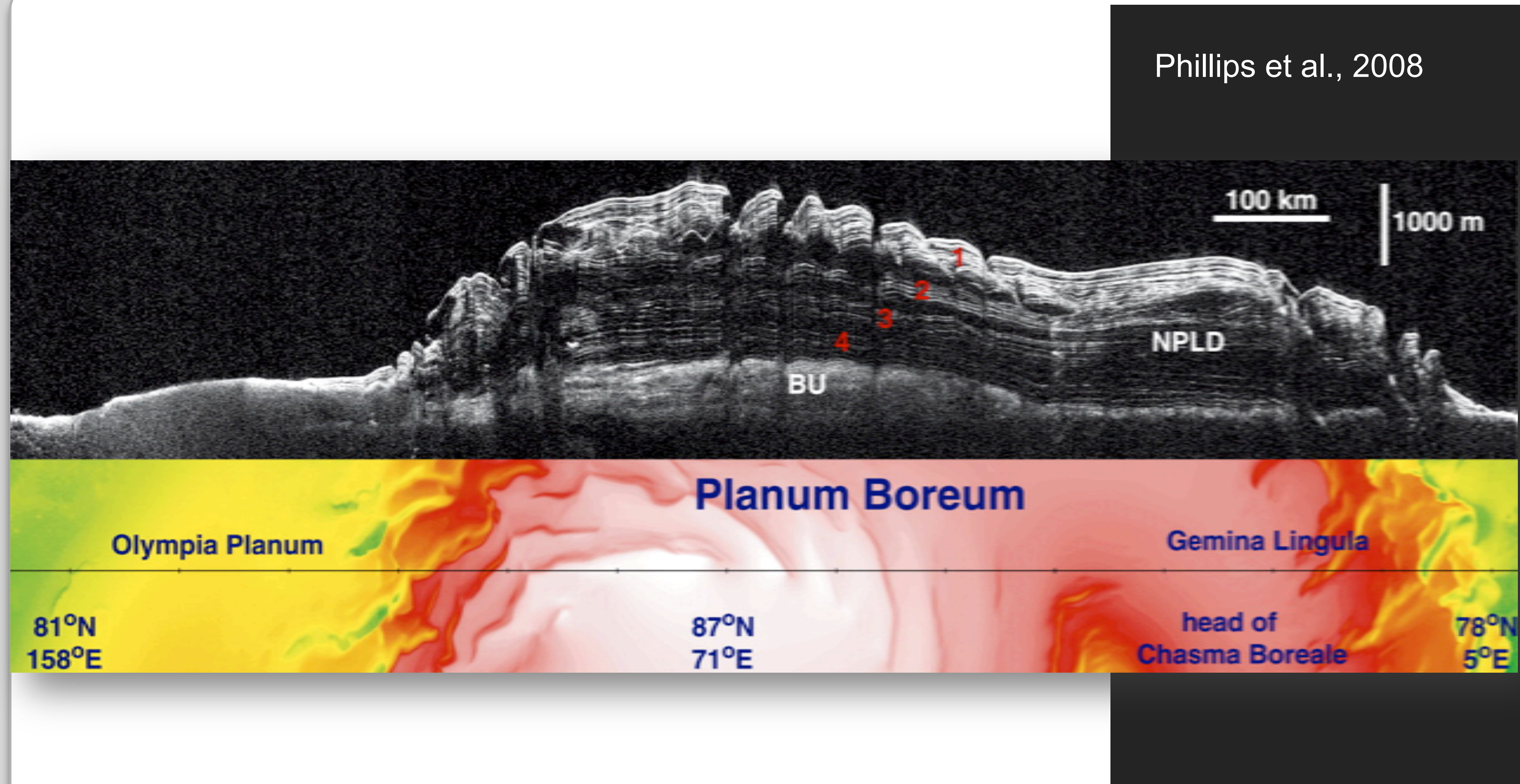


Pratt, 1984

Clay content and extent of bioturbation appear to control content and composition of organic matter in Cretaceous limestone-shale couplets in the Western Interior Seaway of North America.

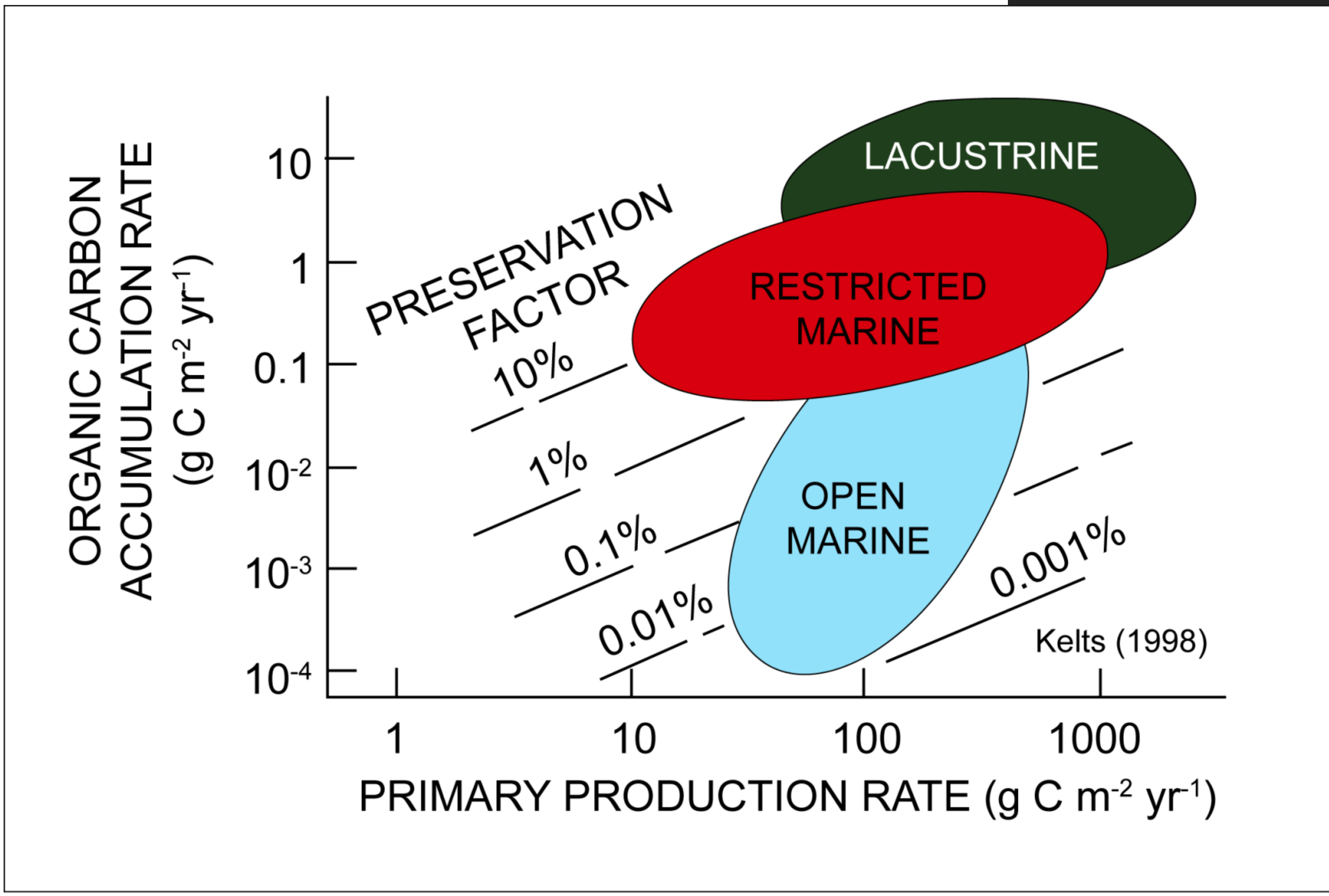
Paul Olsen examining Lacustrine black shale and paleosol gray mudstone in the Triassic-Jurassic Hartford Basin.

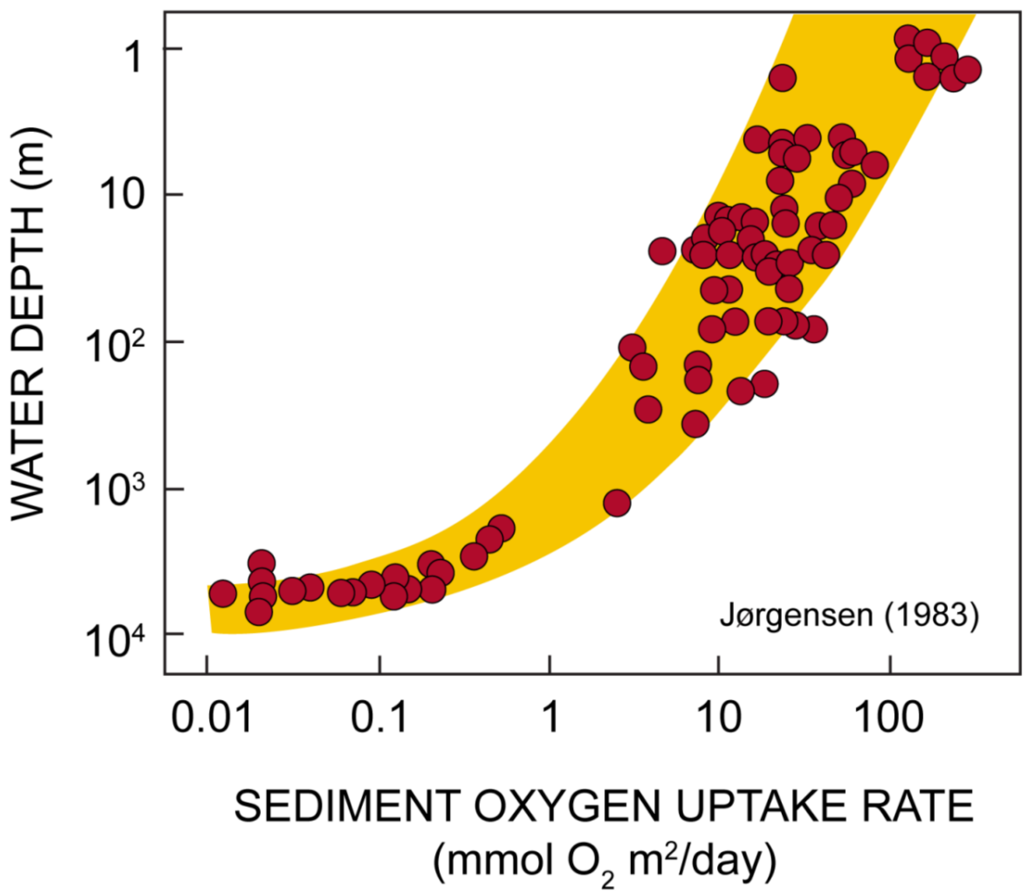
Black shale accumulated during wet phases of climate cycles with a periodicity dominated by precession at 21ky.

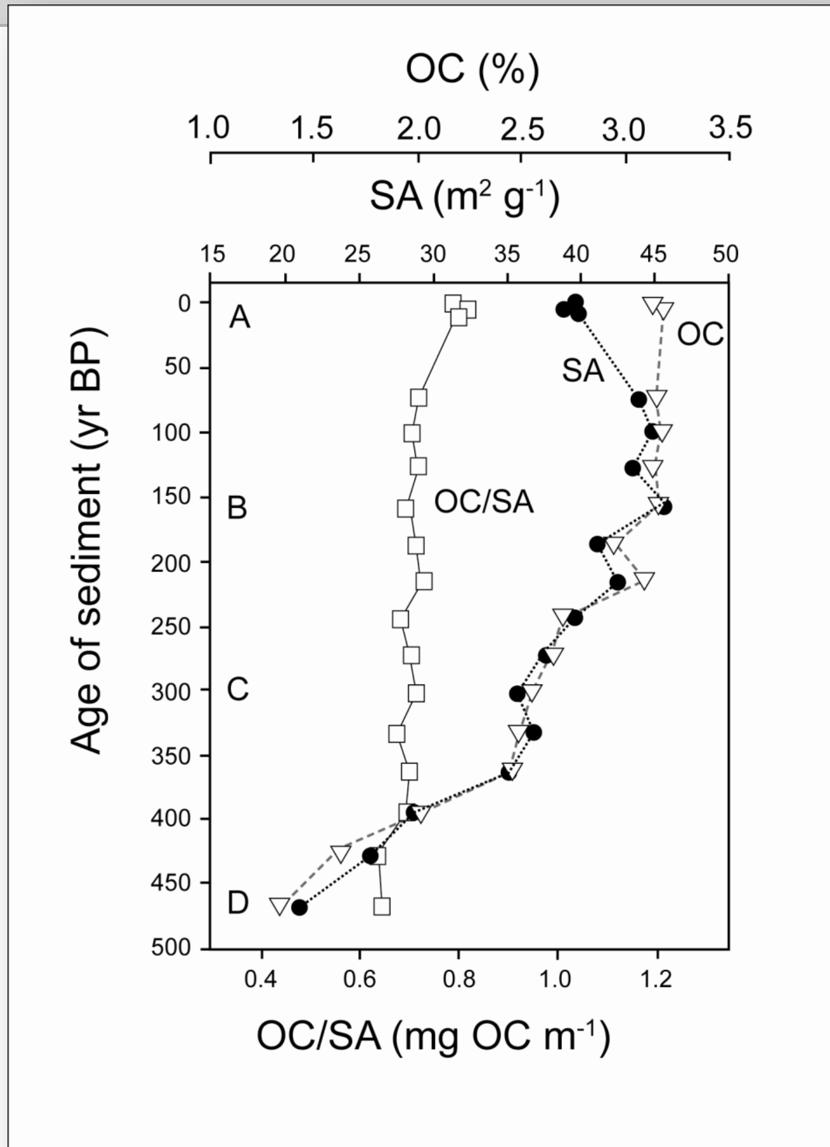


Orbital and rotational periodicities affect insolation at Mars' poles: (i) an obliquity variation (120,000 years), (ii) a climatic precession (51,000 years), and (iii) an eccentricity variation (95,000 to 99,000 years).

Obliquity appears to have the largest influence on Martian climate.

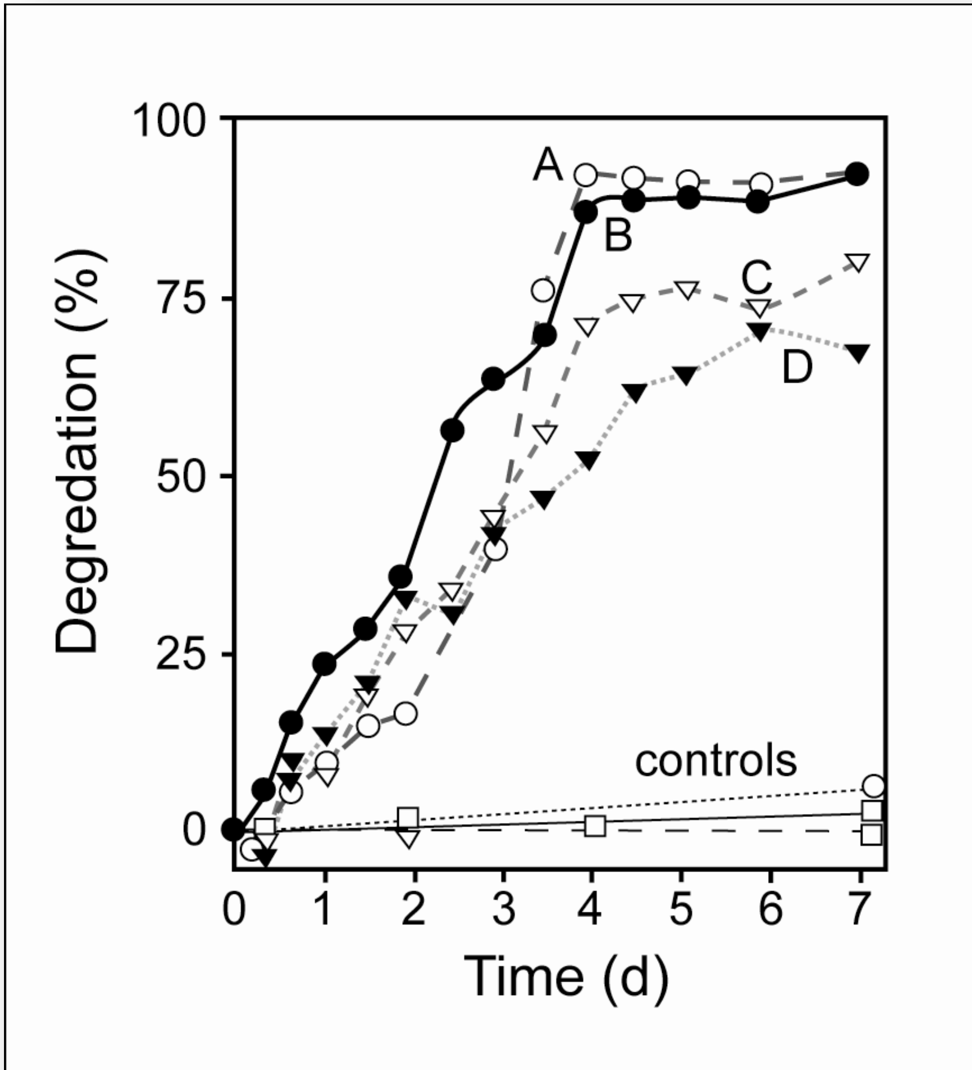

LACUSTRINE
RESTRICTED MARINE
OPEN MARINE
PRESERVATION FACTOR
10%
1%
0.1%
0.01%
0.001%
Kelts (1998)
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
1
10
100
1000
ORGANIC CARBON ACCUMULATION RATE (g C m^{-2} yr^{-1})
PRIMARY PRODUCTION RATE (g C m^{-2} yr^{-1})


WATER DEPTH (m)
1
10
10²
10³
10⁴
0.01
0.1
1
10
100
Jørgensen (1983)
SEDIMENT OXYGEN UPTAKE RATE
(mmol O₂ m²/day)



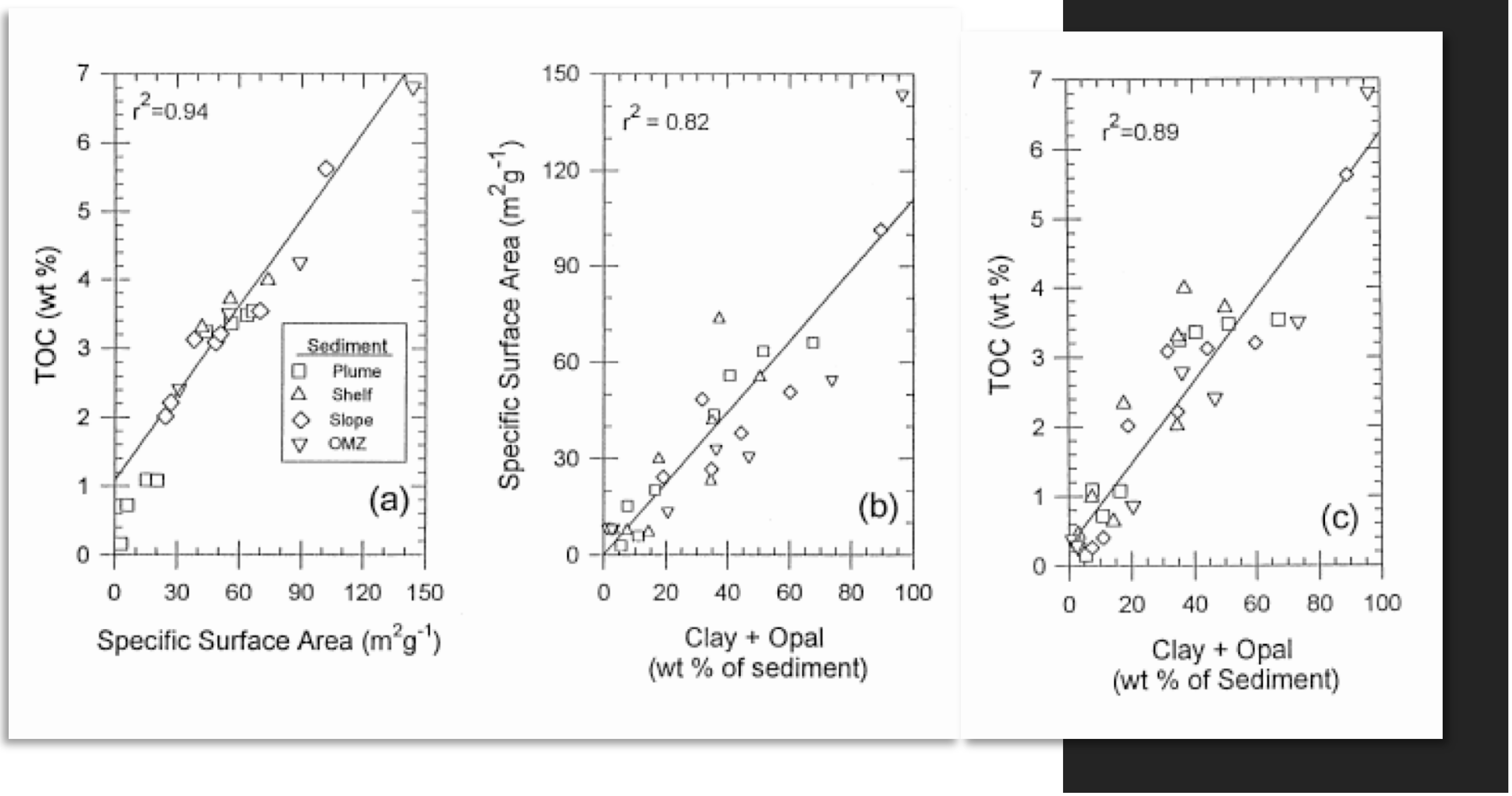
Kell et al., 1994

Organic carbon content and mineral surface area for a sediment core from the continental margin off the Washington coast.



Kell et al., 1994

Degradation of desorbed organic matter from core samples by natural assemblages of aerobic microorganisms.

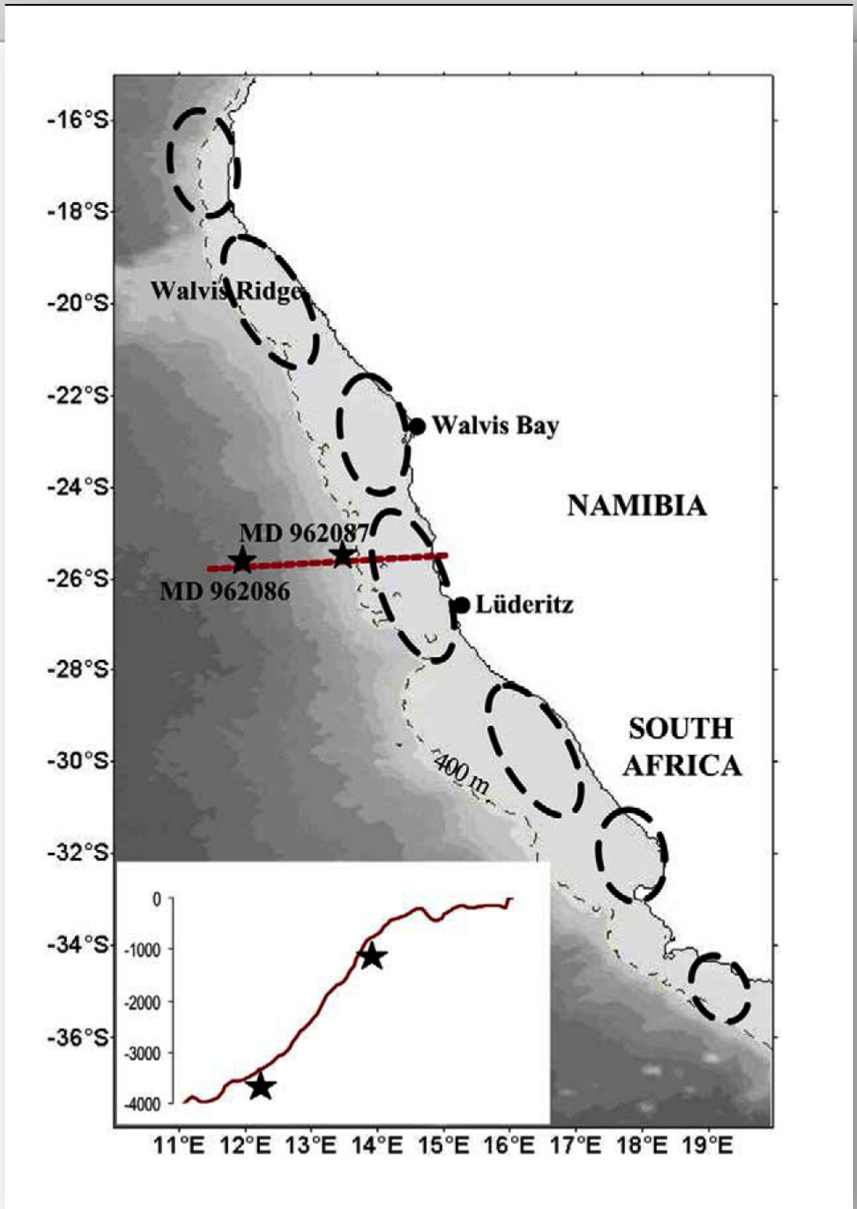


Ranson et al., 1998

Correlations among surface area, content of organic carbon, and content of clay plus opal for samples from the continental margin of Washington.

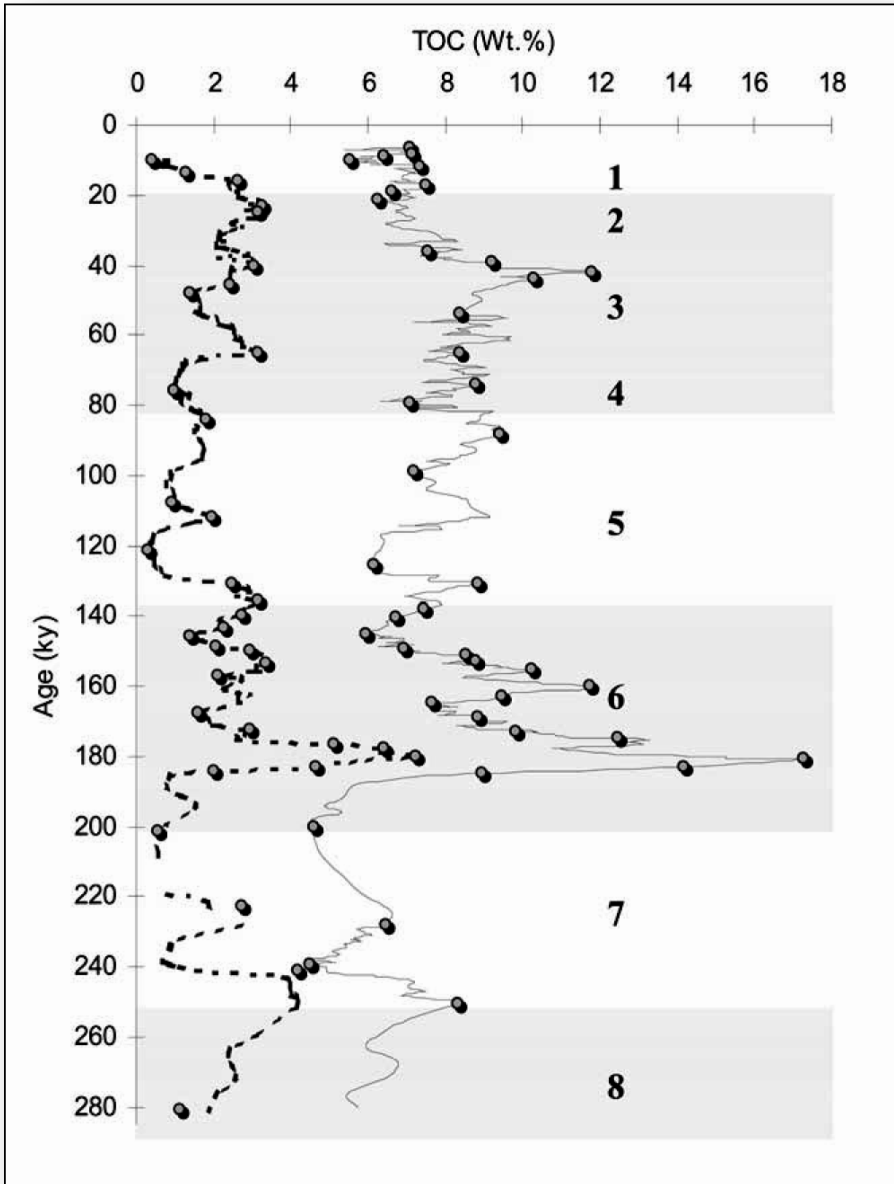
It is not the surface roughness of the terrigenous detrital framework grains that controls the specific surface area of most continental margin sediments, even in the sand and silt fractions, but rather the presence of nonspherical, high surface area-to-volume particles, primarily clays but also oxy-hydroxides and ultra-structured nonorganic bioclasts such as diatom frustules.

Ranson et al., 1998



Pichiven et al., 2004

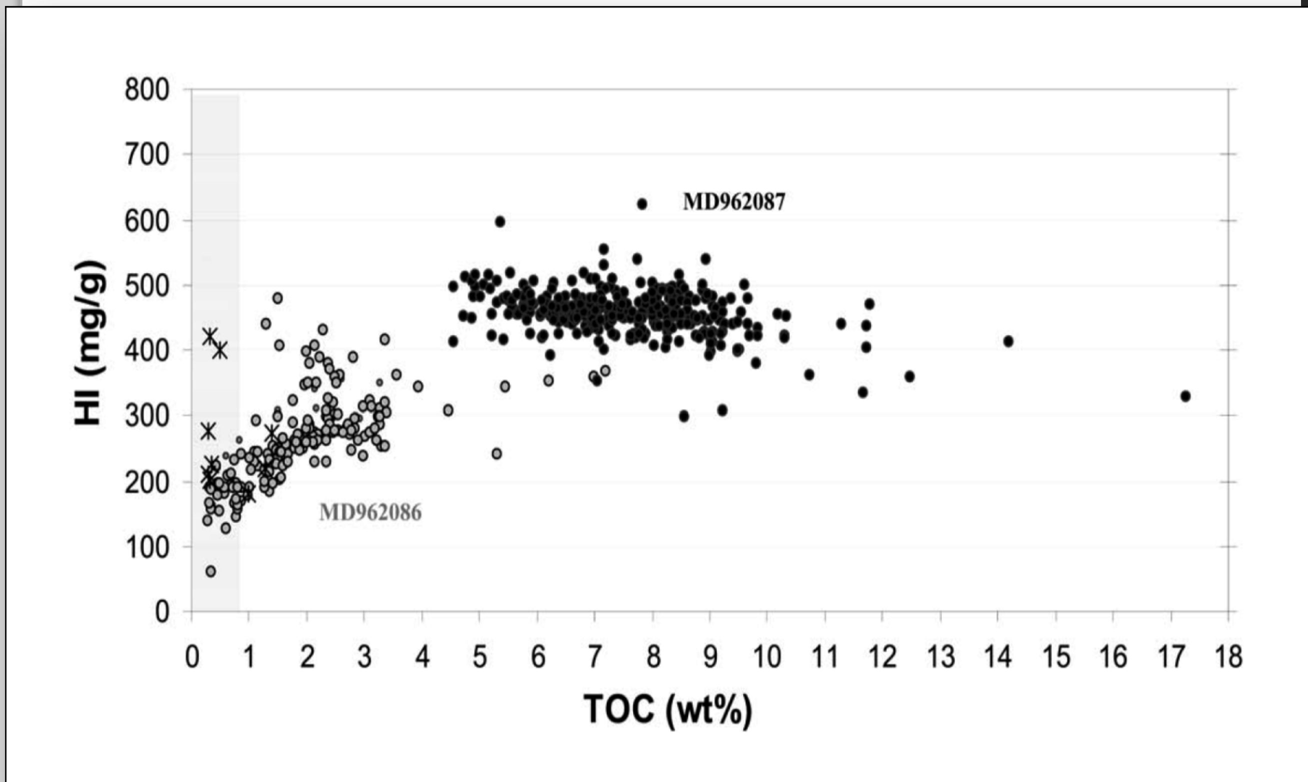
Location of two sediment cores taken on the west coast of Africa under an upwelling zone.



Pichiven et al., 2004

Organic carbon content for core 86 at 3600m (left) and 87 at 1000m (right) water depth on the margin of Namibia.

Glacial isotopic stages are indicated by grey bands and interglacial isotopic stages are indicated by white bands.



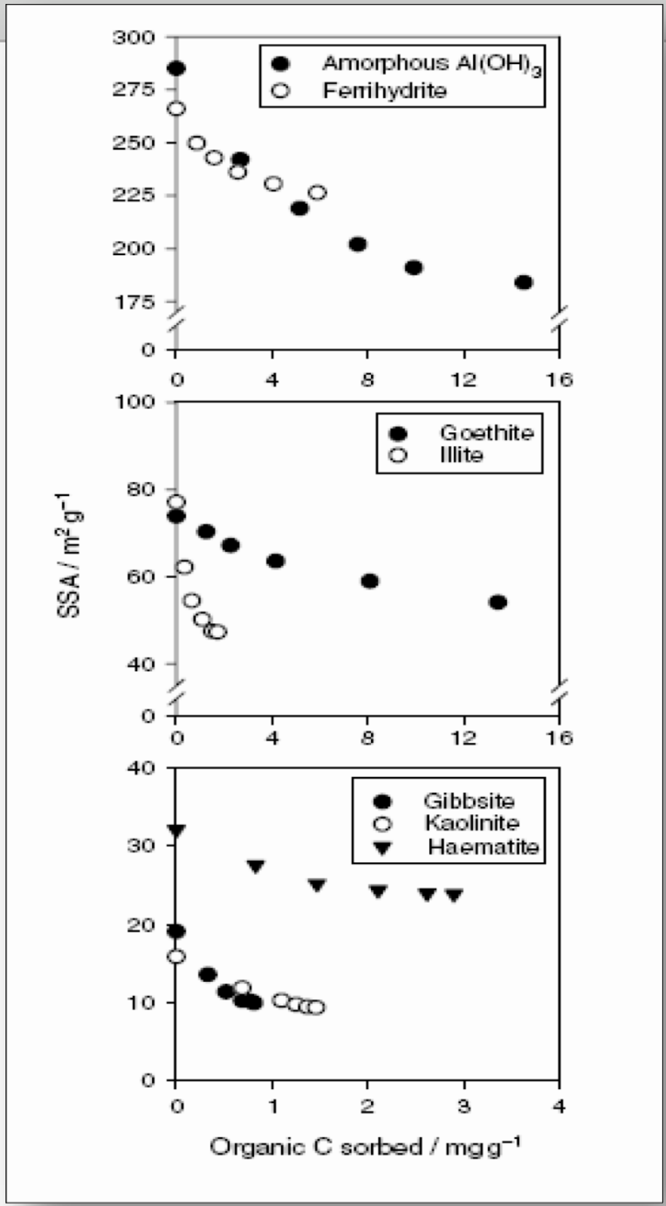
Pichiven et al., 2004

Hydrogen Index (mg/g) versus organic carbon content (wt.%) for core 87 (1000m) and 86 (3600m). High HI indicates a more aliphatic composition for organic matter.

Pichiven et al., 2004

Transmission Electron Microscopy of isolated organic matter from 3600m water depth on the Namibian slope. Pictures G, H, J and I show the structure of the micro-aggregates (μA) at increasing magnifications.

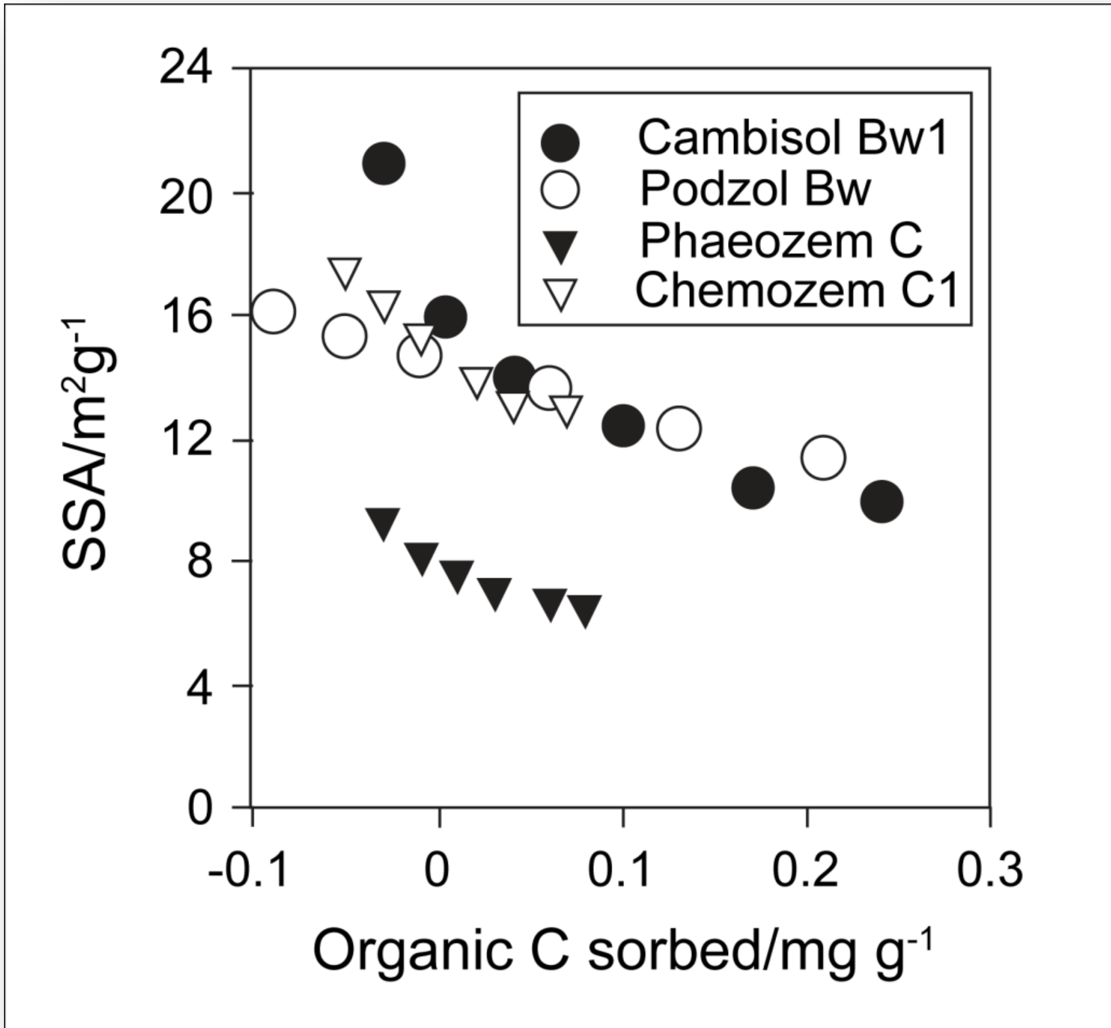
Note that higher magnification reveals ultrastructure of clay particles embedded in organic matter.



Kaiser and Guggenberger 2003

Effect of increasing amounts of sorbed organic C on the specific surface area (SSA) of seven mineral phases.

Rapid initial loss of SSA is inferred to result from filling or clogging of micropores



Kaiser and Guggenberger 2003

Effect of increasing amounts of sorbed organic C on the specific surface area of four soil samples.

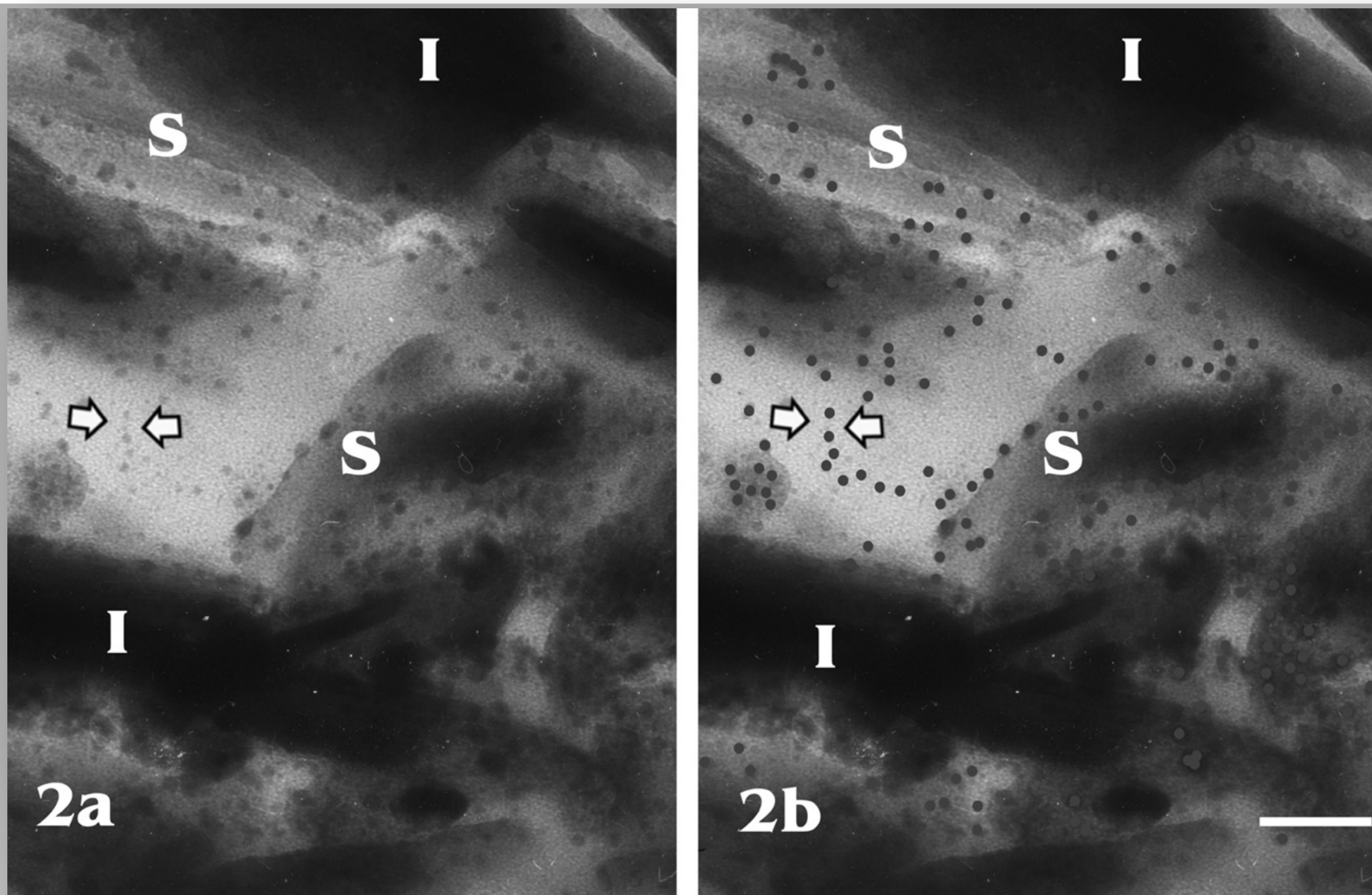
Soil/horizon	Soil color	Hematite	Goethite	Hm/Gt	Fe_2O_3	SOM	Kaolinite	Gibbsite	H	RR	RF
		g kg^{-1}									
PT_A	2.5Y 6/2	0	8	0	29	28.2	13.85	78.68	0	0	0.33
PT_B	2.5Y 7/2	0	5	0	23	13.5	12.85	73.76	0	0	0.29
XH_A	5Y 4/3	0	32	0	82	32.7	52.3	12.89	0	0	0.75
XH_B	2.5Y 5/4	0	37	0	69	10.6	51.1	15.03	0	0	0.8
$TH3_A$	2.5Y 6/4	0	36	0	66	41.7	19.72	67.32	0	0	0.67
$TH3_B$	10YR 6/6	0	37	0	66	17.7	22.03	68.47	0	0	1
$TH1_A$	10YR 5/6	0	99	0	147	50.2	10.69	60.36	0	0	1.2
$TH1_B$	10YR 6/8	0	108	0	145	19.6	10.16	65.44	0	0	1.33
$TH2_A$	10YR 3/3	17	70	0.2	89	79.2	51.08	6.47	0	0	1
$TH2_B$	7.5YR 5/8	26	68	0.28	101	12.1	46.45	4.61	2.5	4	4.1
HH_A	10YR 3/4	0	71	0	138	65.8	59.18	6.18	0	0	1.33
$HH_{A/B}$	10YR 4/6	0	71	0	152	34.9	64.8	7.79	0	0	1.5
HH_B	7.5YR 5/8	31	83	0.27	152	8	62.17	11.12	2.5	4	4.1
$RH1_A$	5YR 4/6	43	34	0.56	122	47.5	67.61	14.54	5	7.5	6.5
$RH1_B$	2.5YR 4/6	46	33	0.58	119	20.6	68.29	13.94	7.5	11.25	9
$RE1_A$	5YR 4/4	51	51	0.5	103	43.3	7.46	59.21	2.5	5	6
$RE1_B$	2.5YR 4/8	60	47	0.56	114	13	8.82	64.13	7.5	15	9.5

Fontes and Carvalho, 2005

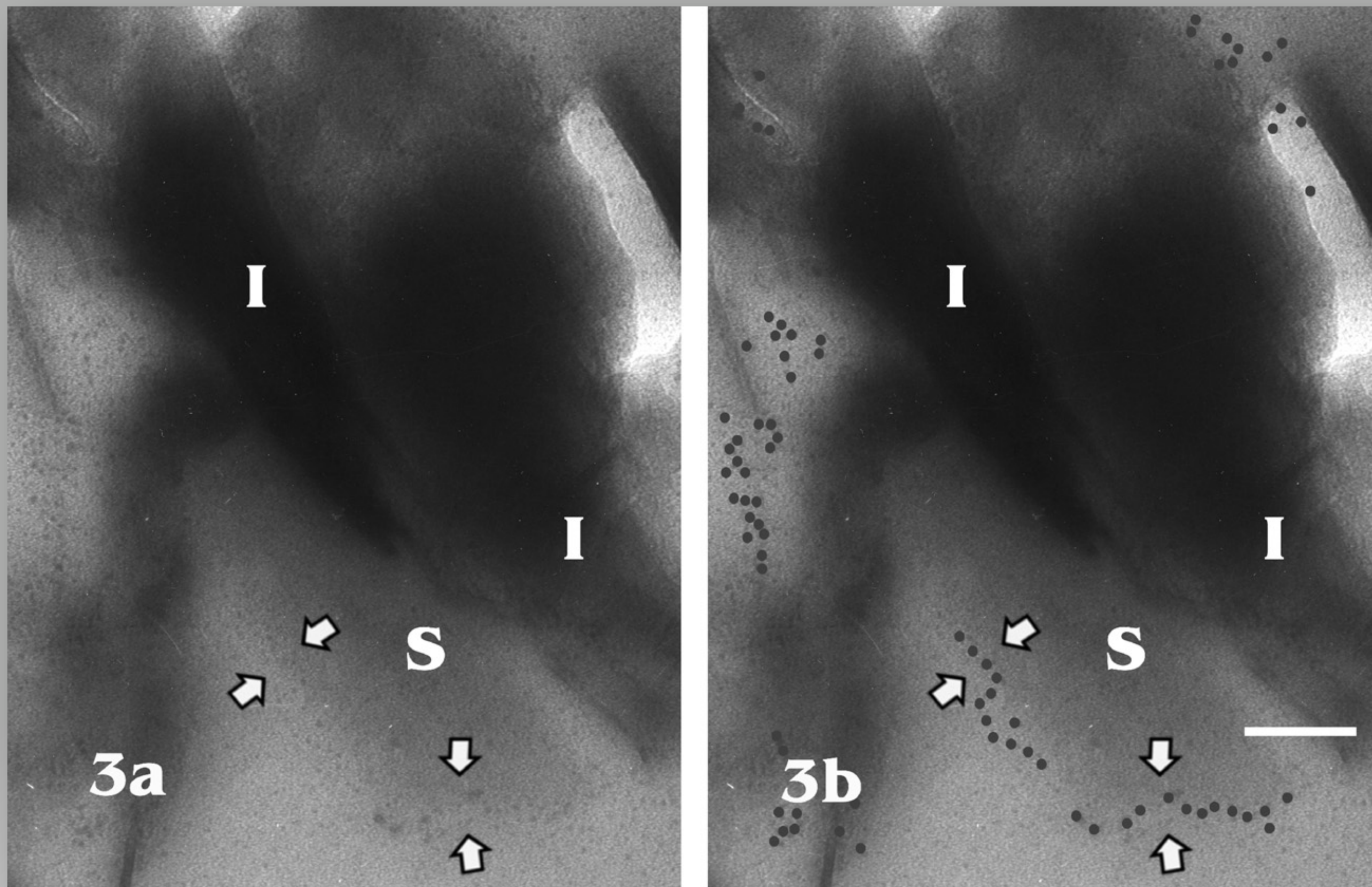
Highlighted column shows the concentration of soil organic matter (parts per thousand) in highly-weathered tropical soils. These soils are red and red-yellow in color and are enriched in iron oxides, gibbsite and kaolinite.

Double arrows marks clay domains.
Lab sediment with illite (90%), smectite (10%), and chitin (10%).
Scale bar = 500 nm.

Curry et al, 2007

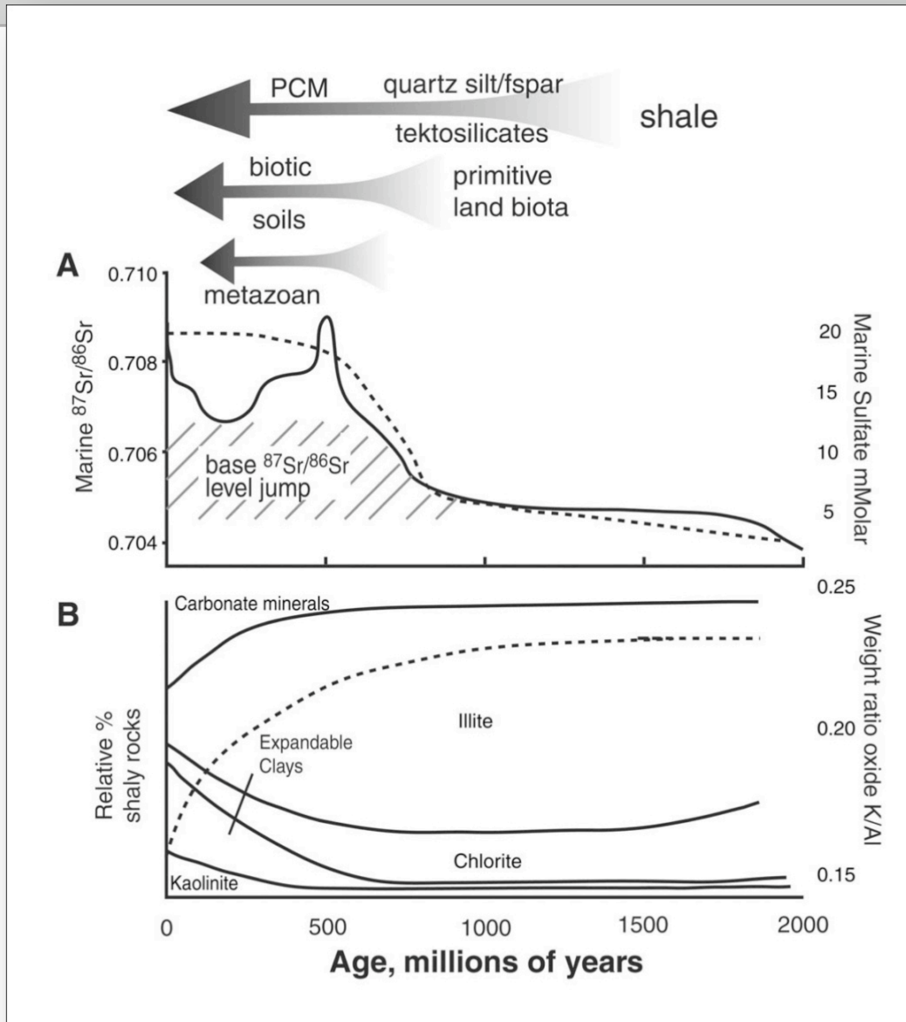


Curry et al, 2007
Illite (90%) and smectite (10%) with 10% chitin undigested.
I, illite; S, smectite. Scale bar = 50 nm.



Curry et al, 2007

Illite (90%) and smectite (10%) with 10% chitin after digestion with chitinase.
I, illite; S, smectite. Scale bar = 50 nm.



Kennedy et al., 2006

A) Solid line represents generalized $^{87}Sr/^{86}Sr$ seawater evolution from carbonate sediments.

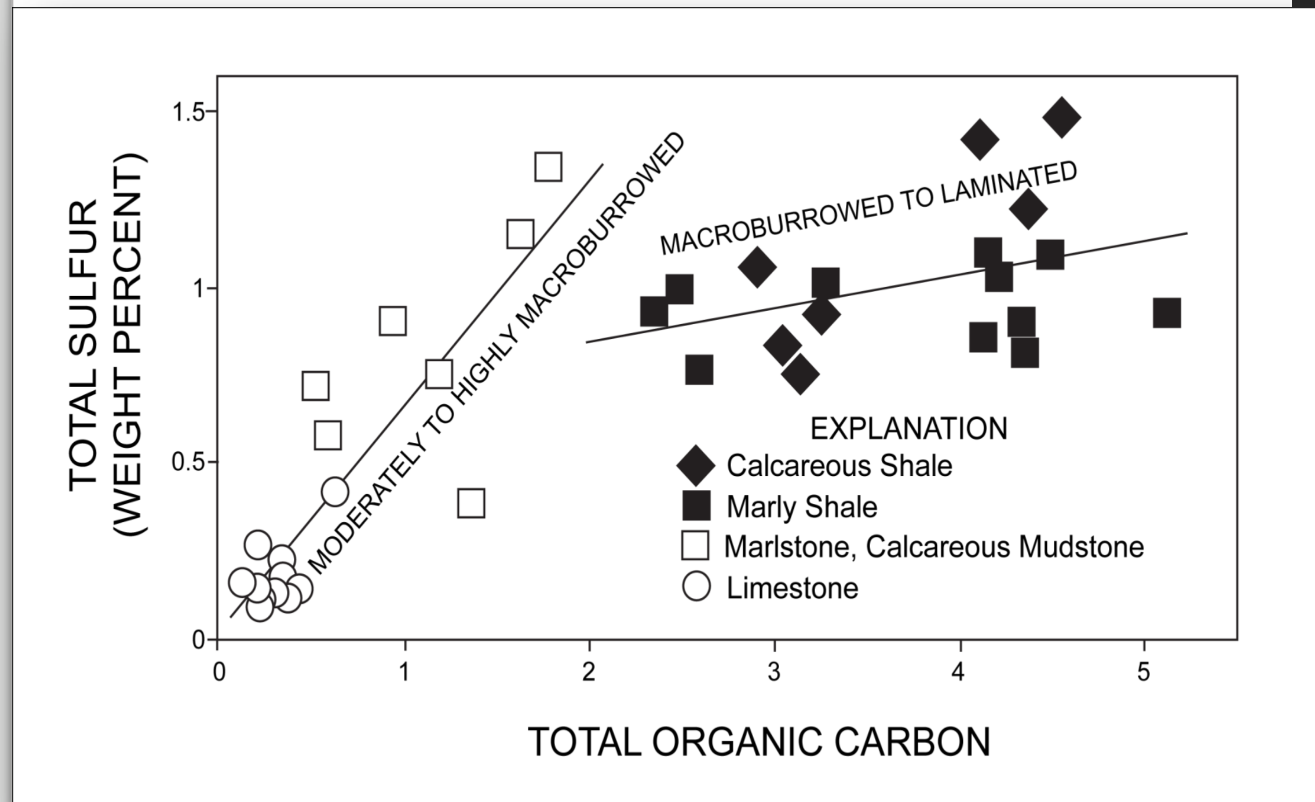
Dashed line represents the rise in concentration of dissolved marine sulfate, which coincides with general rise in atmospheric oxygen .

B) Increase in expandable clays and kaolinite (PCM) into the Phanerozoic relative to illite, mica, and chlorite within shale, reflecting illitization as well as enhanced chemical weathering and production of pedogenic clay minerals associated with biotic soils.

Half graben on the Oregon basalt plateau with a chain of alkaline saline lakes on the fault-bounded side of the valley.

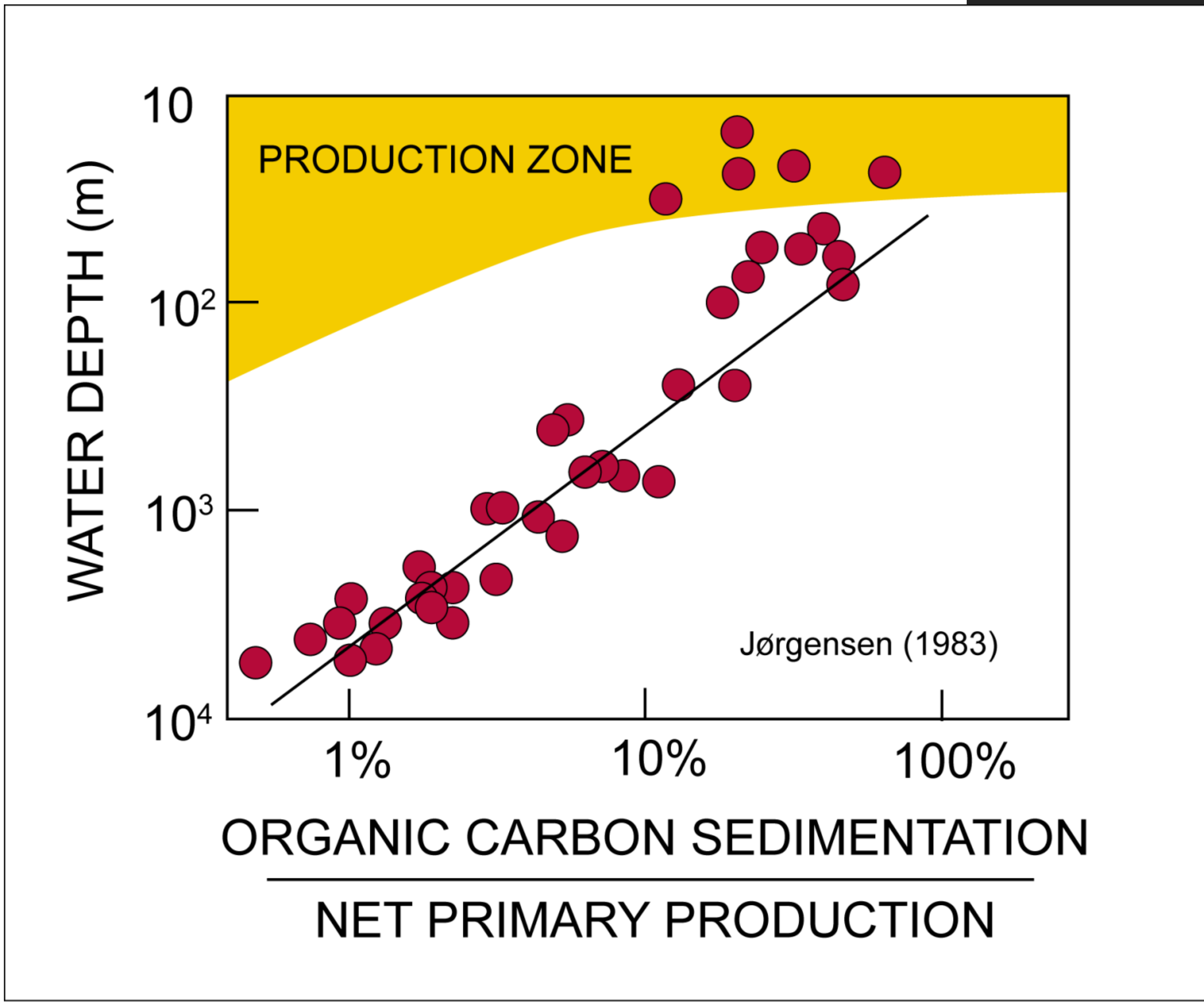
Dust devil eroding clay and salt deposits from a dry lakebed on the Oregon basalt plateau.

Core barrel inserted into lakebed sediments on the Oregon basalt plateau.



Pratt, 1984

Variations in concentration of total sulfur and organic carbon for interbedded limestone and shale


10
PRODUCTION ZONE
10^2
10^3
10^4
WATER DEPTH (m)
Jørgensen (1983)
1%
10%
100%
ORGANIC CARBON SEDIMENTATION
NET PRIMARY PRODUCTION

Thick sequence of black shale in La Luna Formation, Venezuela.

These marine deposits accumulated under an upwelling zone on the northwest margin of Cretaceous South America. Organic carbon contents are in the range of 5-7.5 wt. %.

Alkaline saline lake on the Oregon basalt plateau with desiccated algal-bacterial mats on the shore and hydrated mats in the water column.

Cretaceous marine shale in the Italian Apennines with bedding periodicities at orbital frequencies of 105, 40, 26, and 19 kyr.