Soils, Slopes and Source Rocks: the Roles of Soil Chemistry and Nutrient Delivery to Source Rock Deposition in Rift Lakes*

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Search and Discovery Article #40366 (2008)
Posted November 20, 2008

*Adapted from oral presentation at AAPG Annual Convention, San Antonio, TX, April 20-23, 2008

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Abstract

Lacustrine source rocks in rift basins occupy a distinct position in the stratigraphy of the rift fill, typically occurring in the late rift sequence. Examples include the Early Cretaceous rifts of the South Atlantic margin and the Late Cretaceous rifts of north-central and eastern Africa. Lacustrine source rocks also exhibit strong geographic differences in quality, for example, in equatorial west Africa, changing in both TOC content and organic matter type with respect to the paleo-equator. Studies of the Lower Cretaceous lacustrine shales on the South Atlantic suggest that organic productivity triggered by highly elevated nutrient fluxes led to deposition of the richest source rock intervals.

We hypothesize that soils in drainage basins surrounding the rift lakes are the critical link between climate, rift tectonics and topography and the deposition of rich source rocks. We test this hypothesis through the application of the computer program, CENTURY, which simulates soil chemistry. Our results show that the fluxes to groundwater of key organic nutrients, C, P, N and S are highly sensitive to the slope gradient in drainage basins surrounding a rift lake, increasing as the topography degrades during late stages of rifting. Fluxes are also sensitive to rainfall levels, decreasing substantially as precipitation decreases. These results suggest that nutrient flux to rift lakes and, therefore, organic productivity increase: (1) as topographic relief declines; and (2) in wetter climates.

We apply these models to the topography of the Rio Grande rift system, where relief decreases from north to south along the rift axis. Even where precipitation is held constant, nutrient flux to groundwater increases as much as tenfold from north to south. Changing precipitation can accentuate these differences.

Soils, Slopes and Source Rocks:

The Roles of Soil Chemistry and Nutrient Delivery to Source Rock Deposition in Rift Lakes

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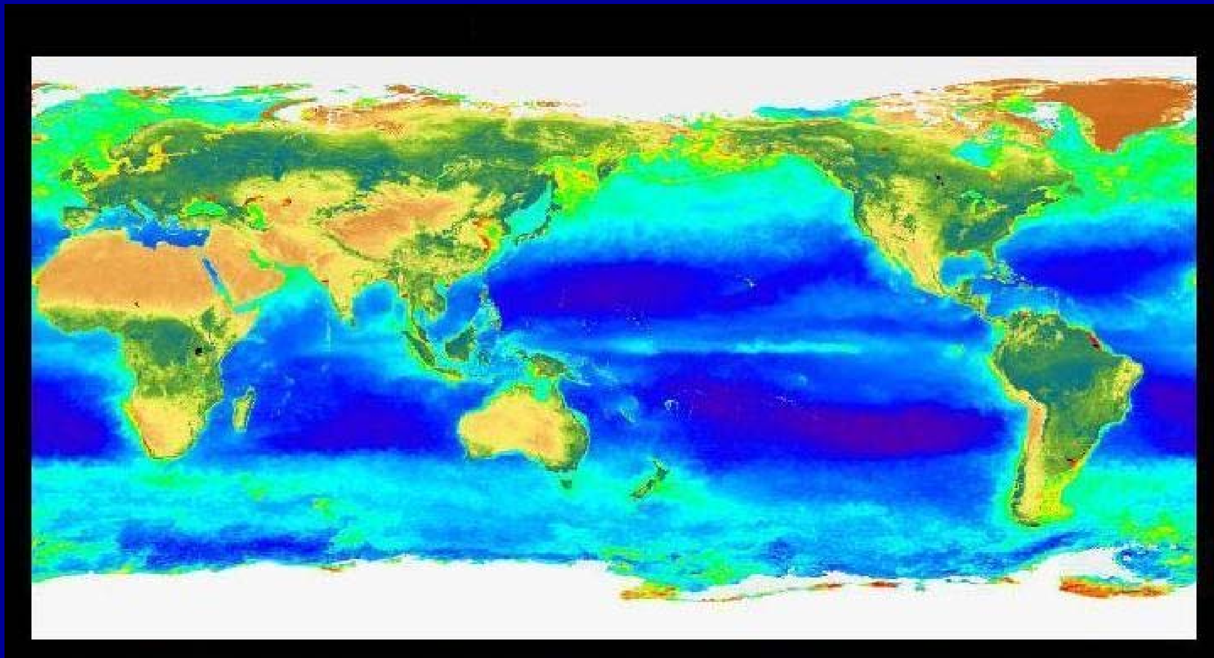
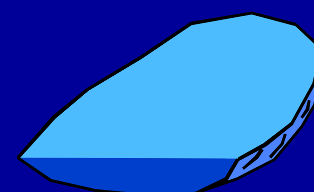
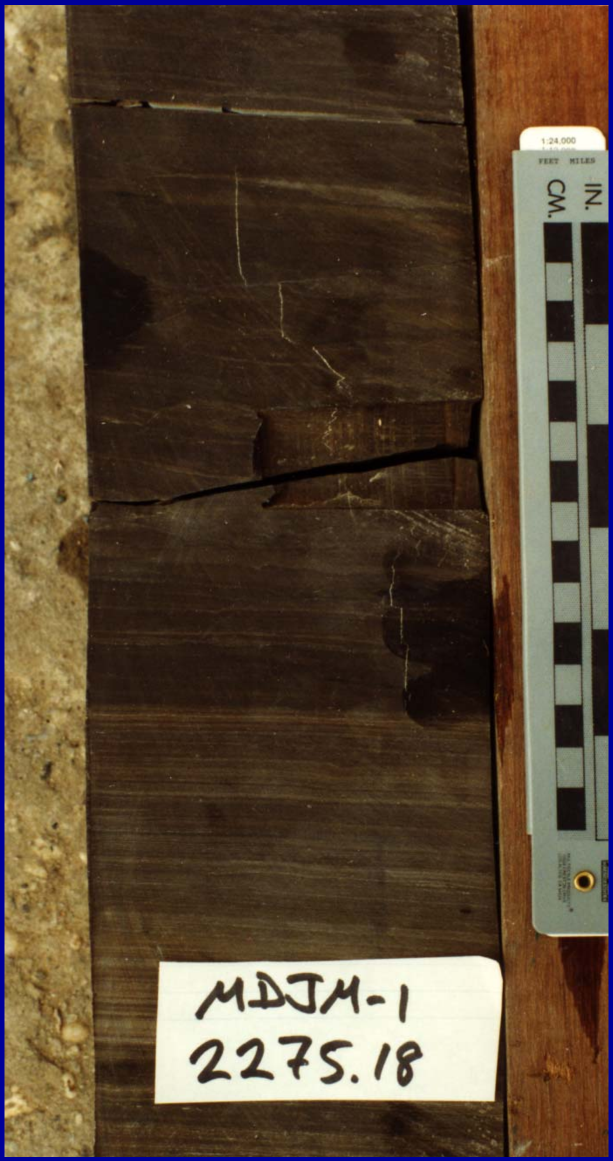


Oceans versus lakes:

Lakes are tiny!





Consequences for lacustrine source rock models

1. Lacustrine source rocks and climate
2. Lacustrine source rocks and topography
3. Apply soil chemistry model to lacustrine source rock deposition

Marnes Noires Formation, Congo Basin

Average TOC: 6%, Oil-prone kerogen

Average thickness: 200 m

One effect of small size of lakes

<u>Residence Time - Oceans</u>

Water: 3200 years

Carbon: 350 years

Nitrogen: 2000 years

Phosphate: 100,000 years

<u>Residence Time - Lakes</u>

Lake Superior – 190 years
Lake Turkana – 12.5 years
Lake Tanganyika – 440 year

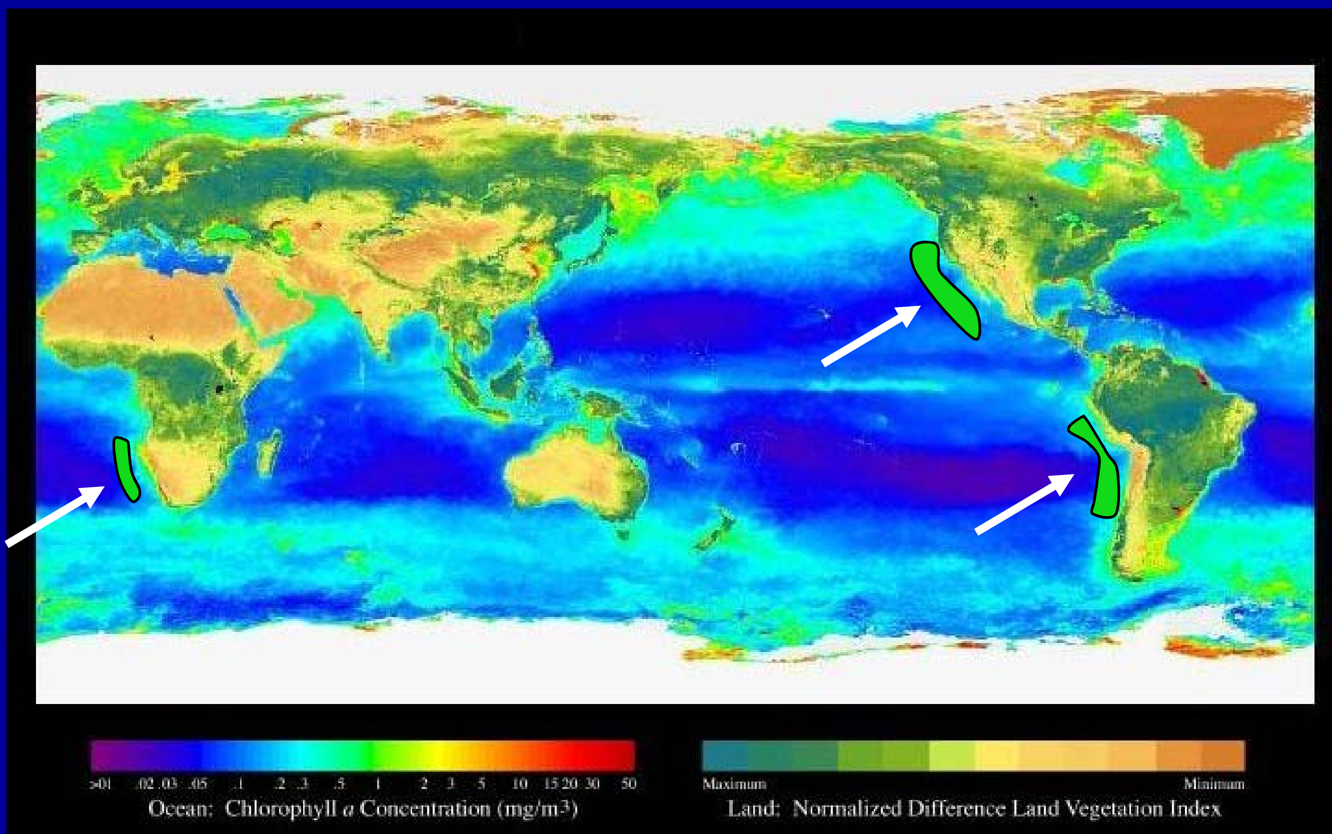
Lake Superior – 8 years
Blue Lake (Australia) – 3 years

Lake Malawi – 9 years

Lake Malawi – 90 years

Another effect of small size of lakes

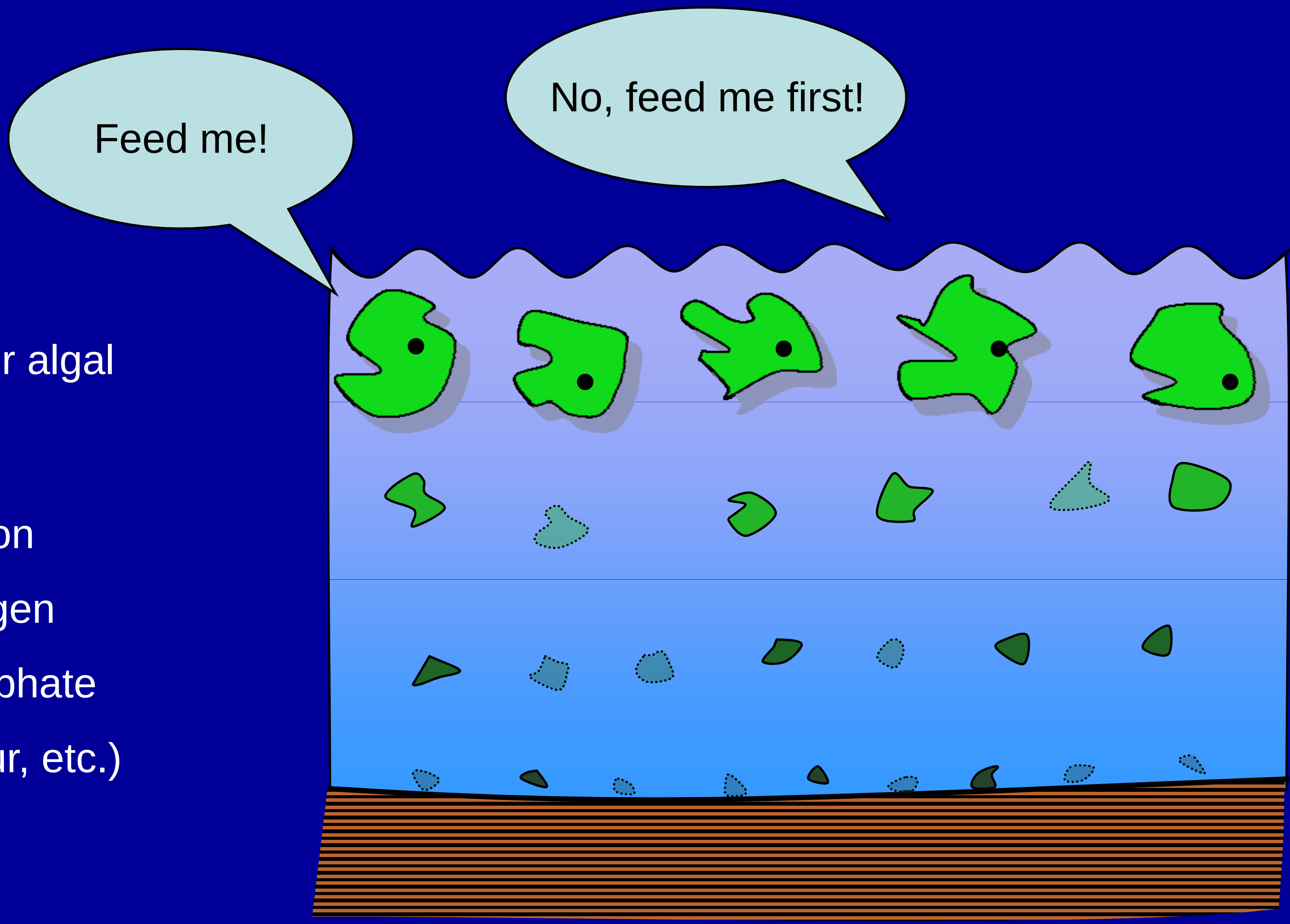
<u>Focused Nutrient Delivery</u>

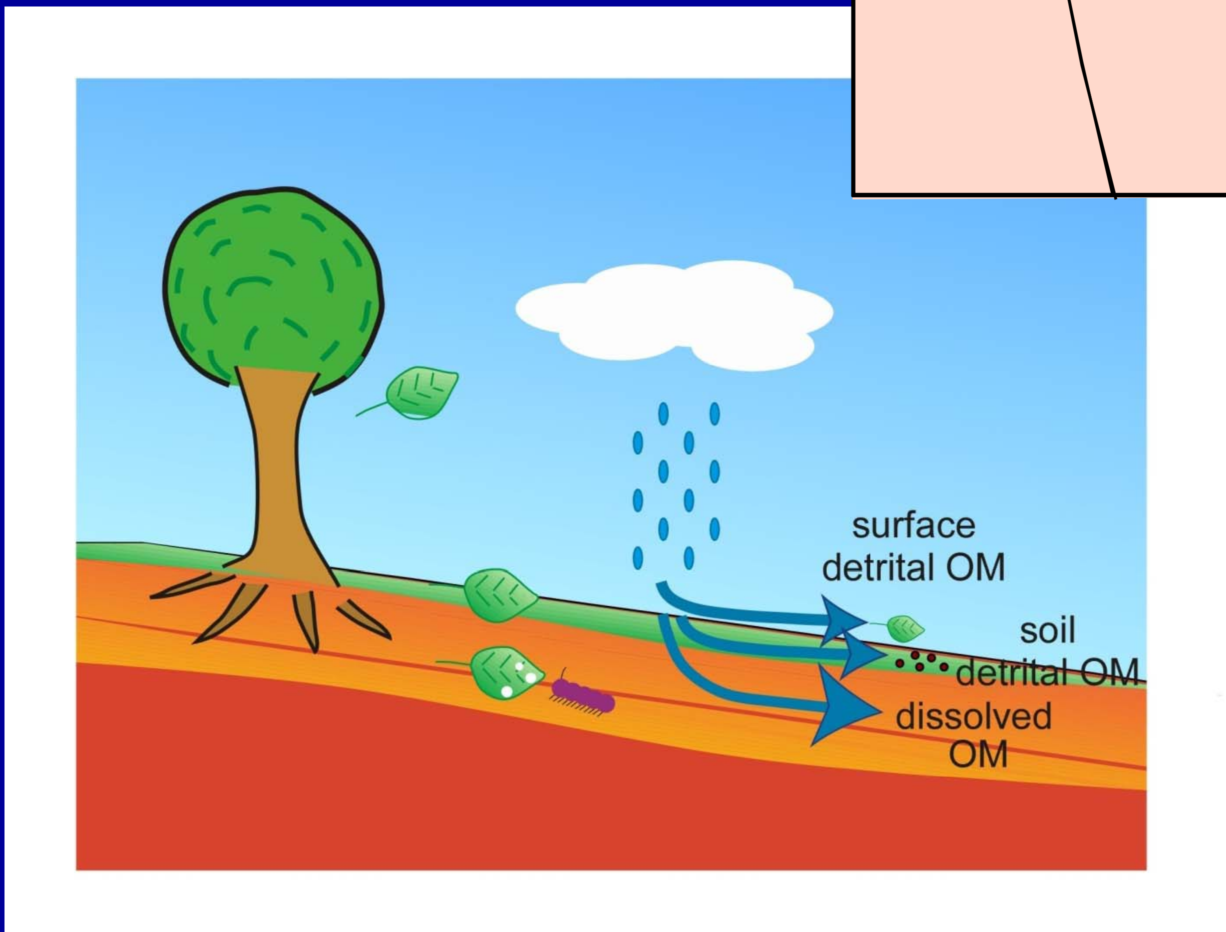


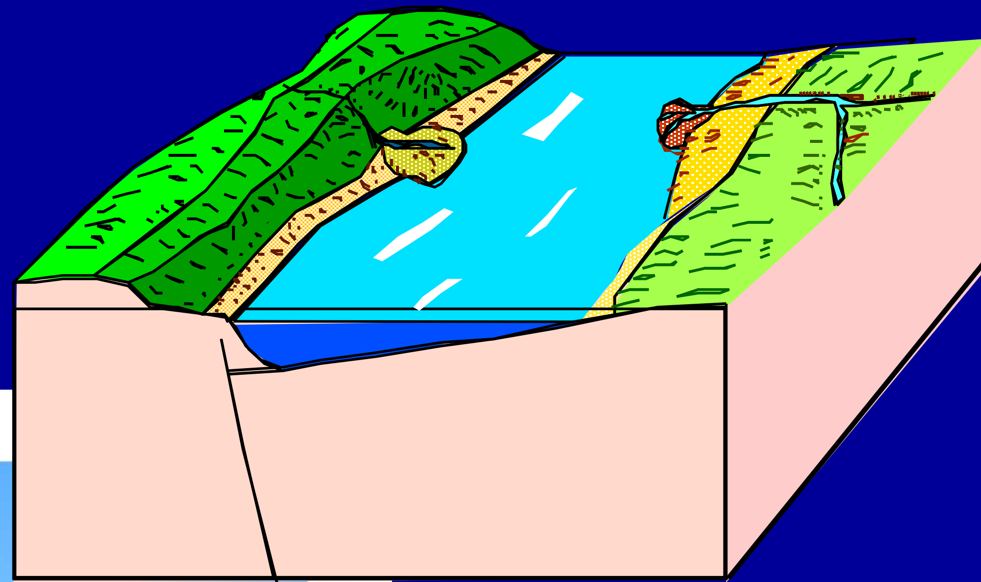
Oceans are capable of sustained focused nutrient deliver, but lakes are not.

Nutrients for algal growth are:

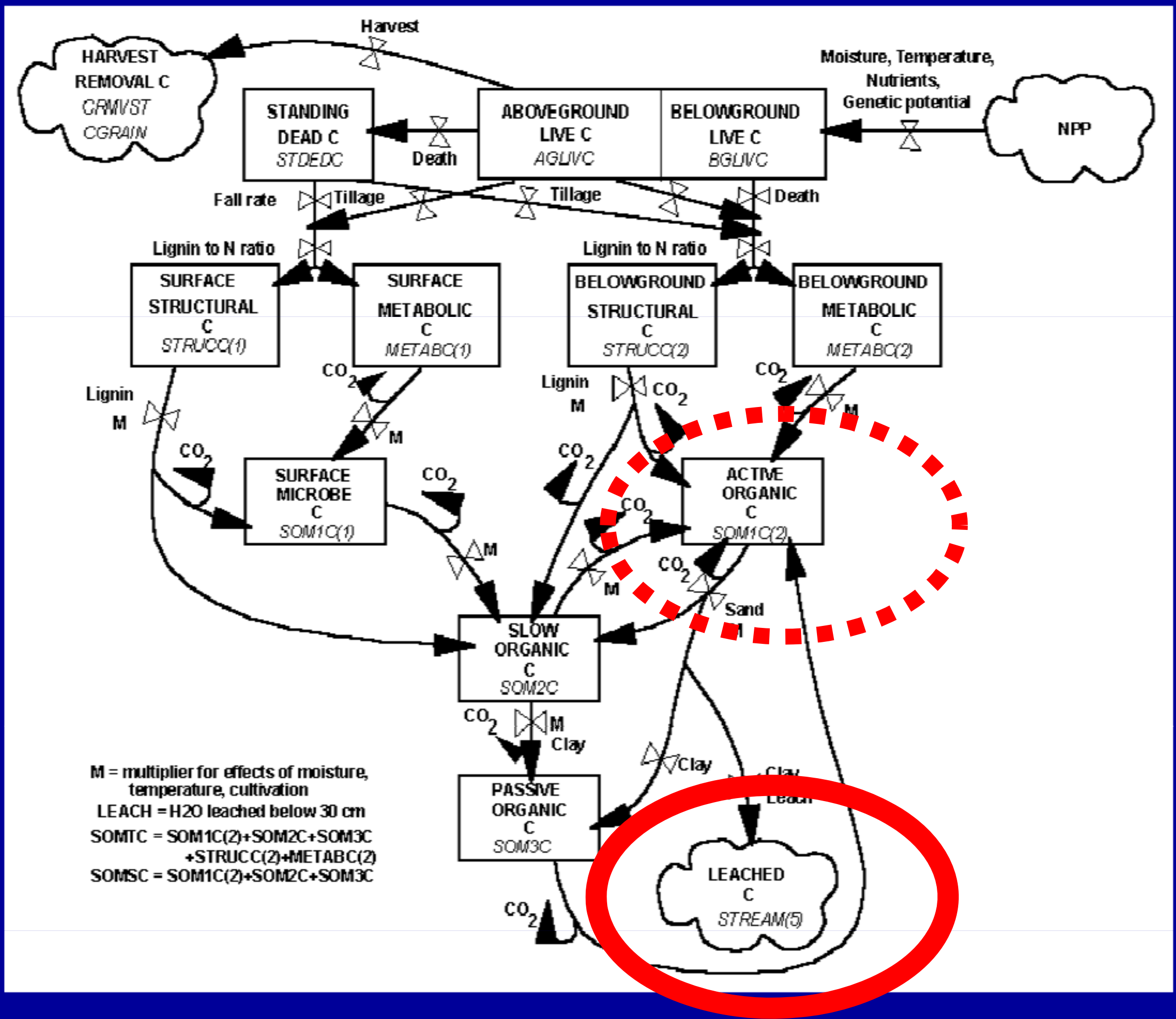
- Carbon
- Nitrogen
- Phosphate
- (Sulfur, etc.)




surface
detrital OM
soil
detrital OM
dissolved
OM



CENTURY SOIL CHEMISTRY MODEL



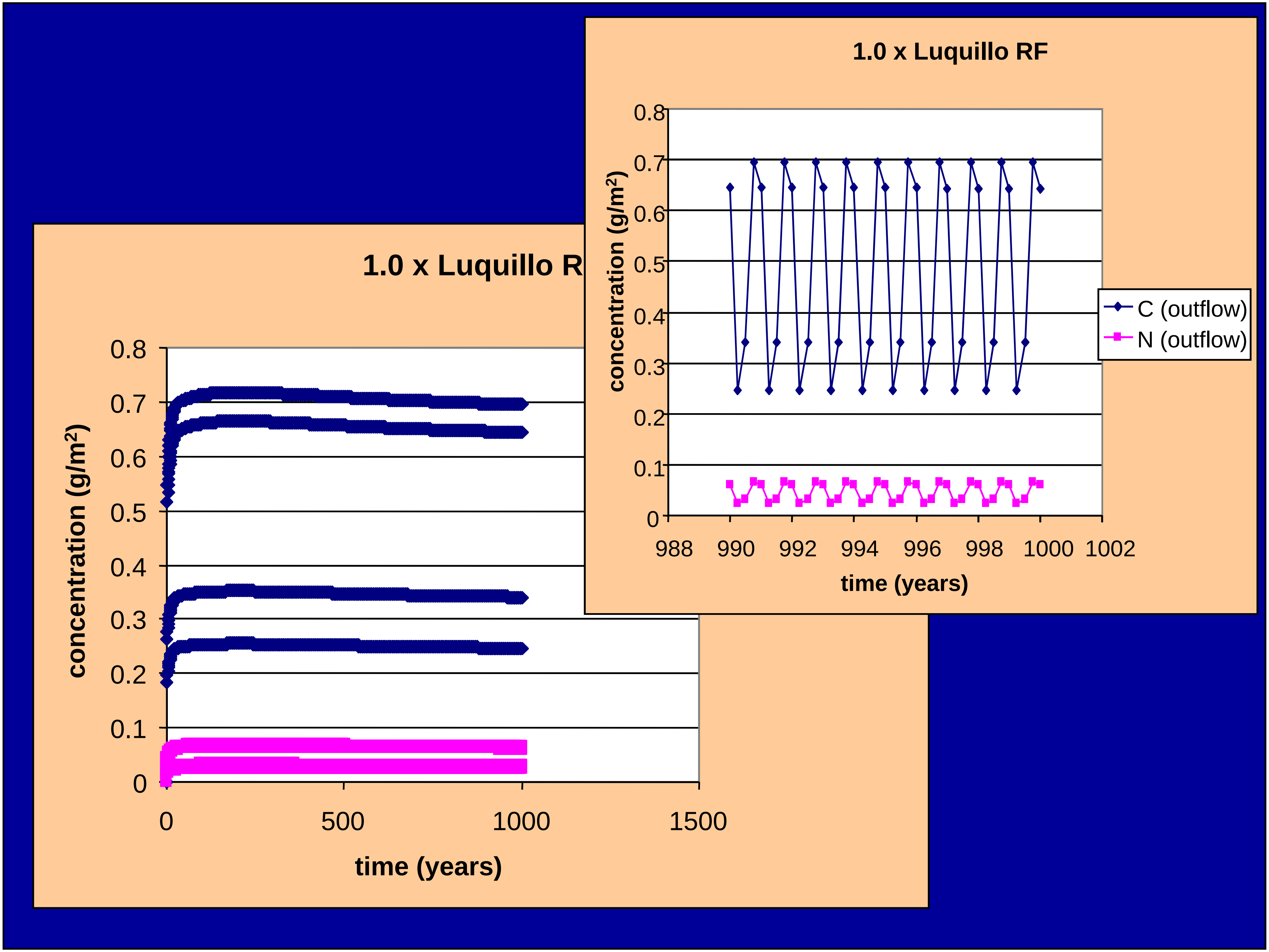
Flow diagram for the soil carbon submodel.

A complex box model that simulates the transfer of nutrients between different pieces of the soil and biological systems.

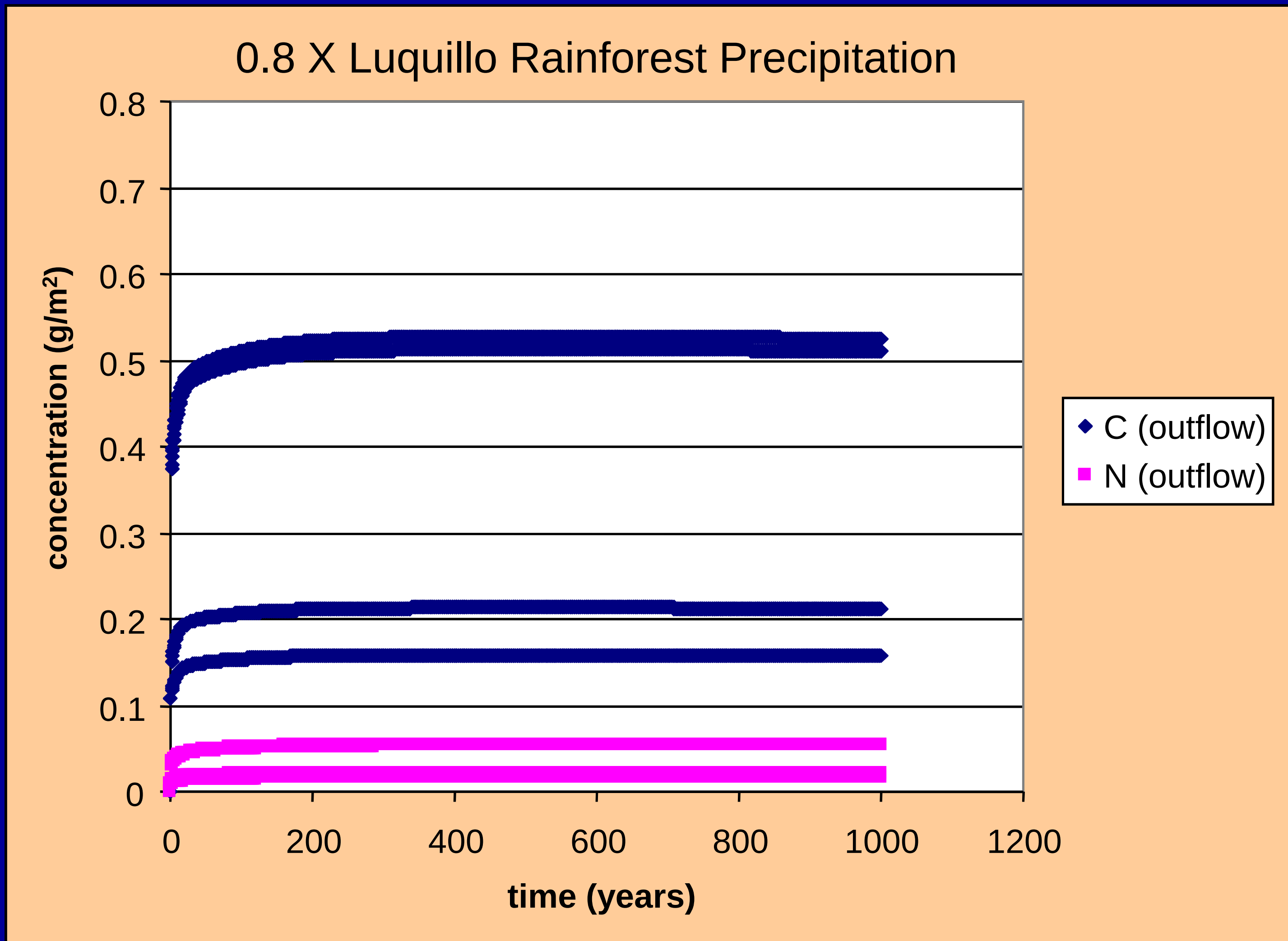
Linked submodels include:

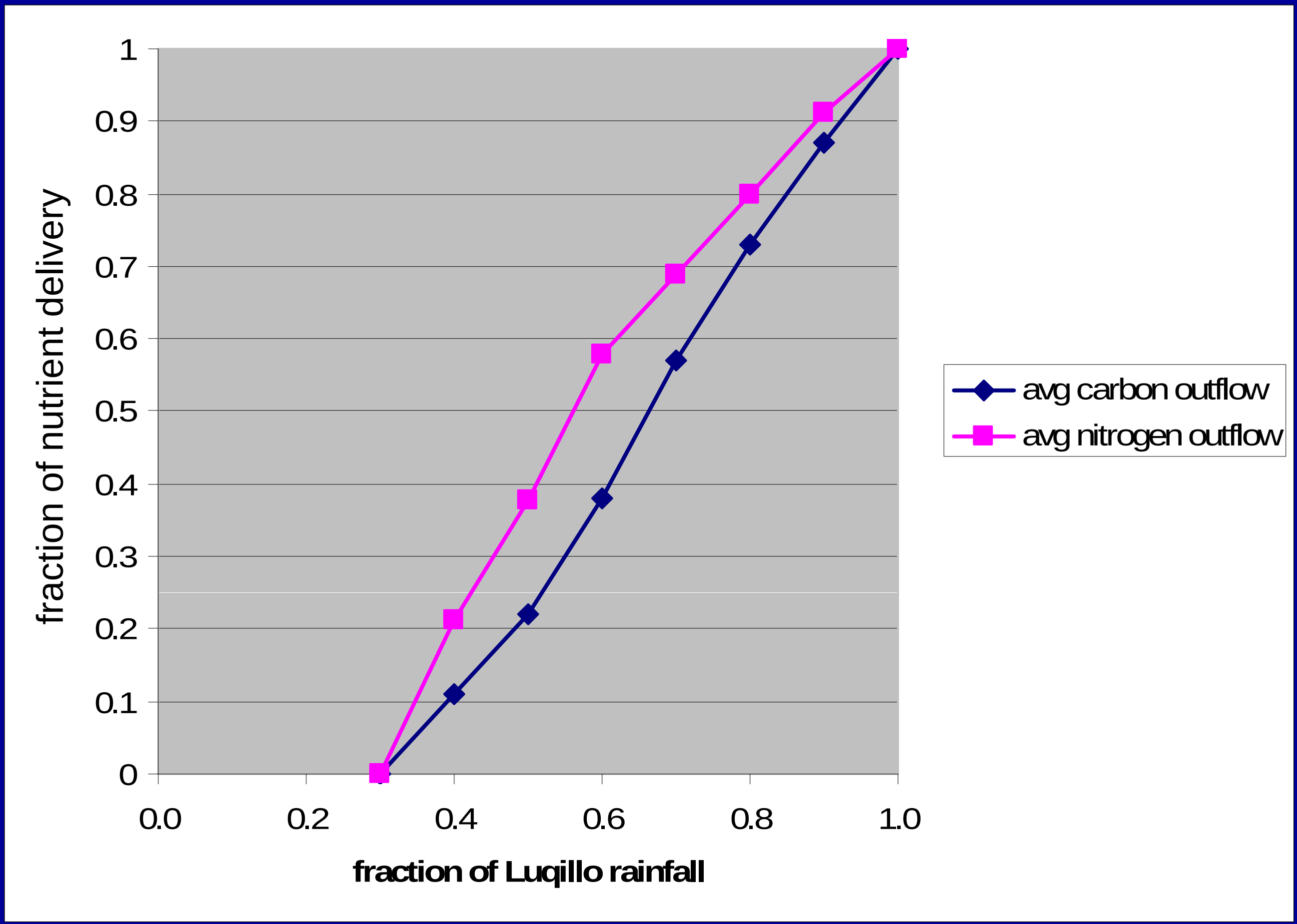
C, N, P, S

Model can simulate flux of nutrients to groundwater



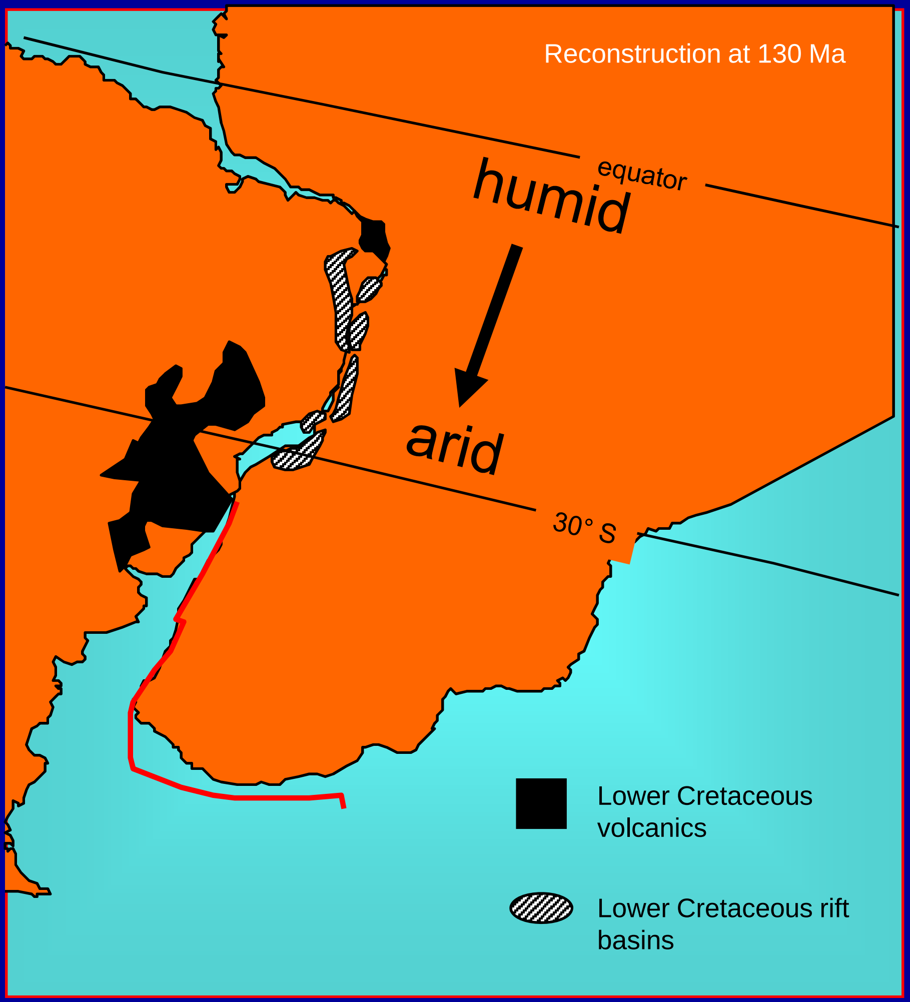
1.0 x Luquillo R
concentration (g/m²)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
500
1000
1500
time (years)
1.0 x Luquillo RF
concentration (g/m²)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
988
990
992
994
996
998
1000
1002
time (years)
C (outflow)
N (outflow)


0.8 X Luquillo Rainforest Precipitation
concentration (g/m²)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
time (years)
C (outflow)
N (outflow)

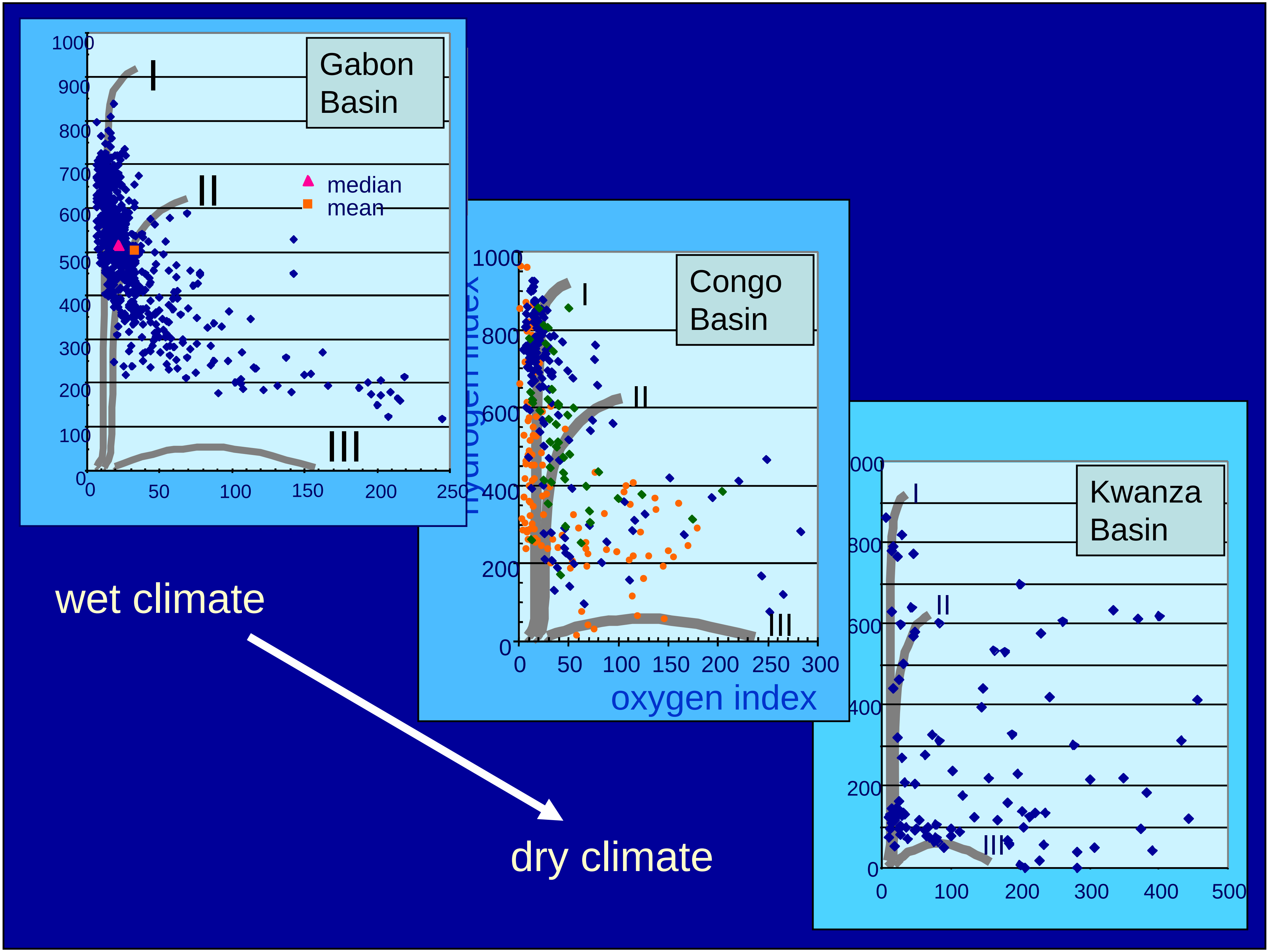


As rainfall decreases, nutrient delivery to groundwater falls sharply

SOUTH ATLANTIC RIFT BASINS



modified from Rabinowitz and LaBrecque, 1979, Scotese and Denhan, 1988, White and McKenzie, 1989 Mello et al., 1994.

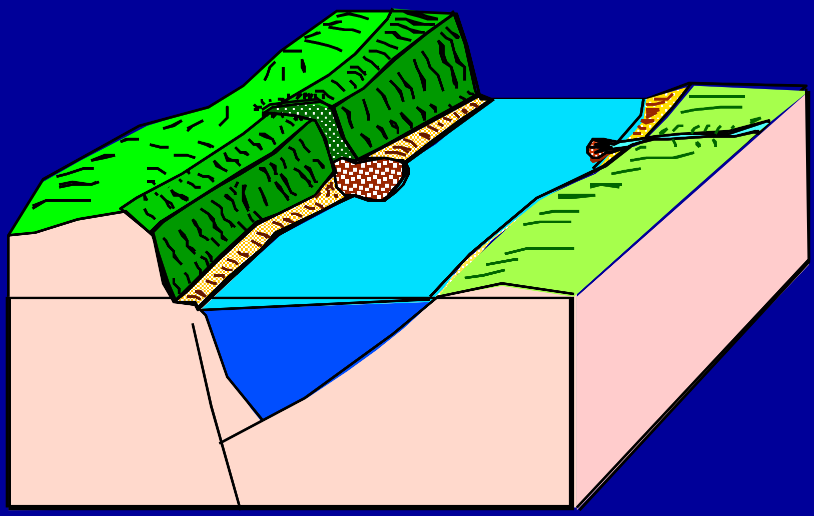


Gabon Basin
median
mean
I
II
III
Congo Basin
hydrogen index
oxygen index
Kwanza Basin
wet climate
dry climate

Nutrient Delivery and Topography

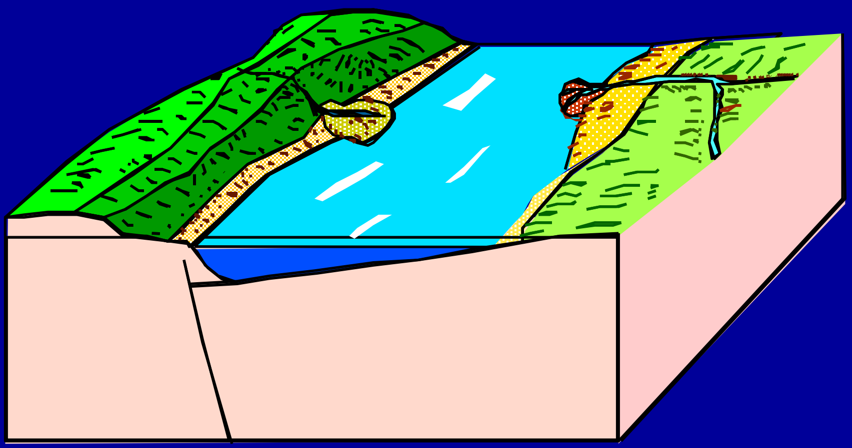
Active Rift Stage

Subsidence > Sedimentation

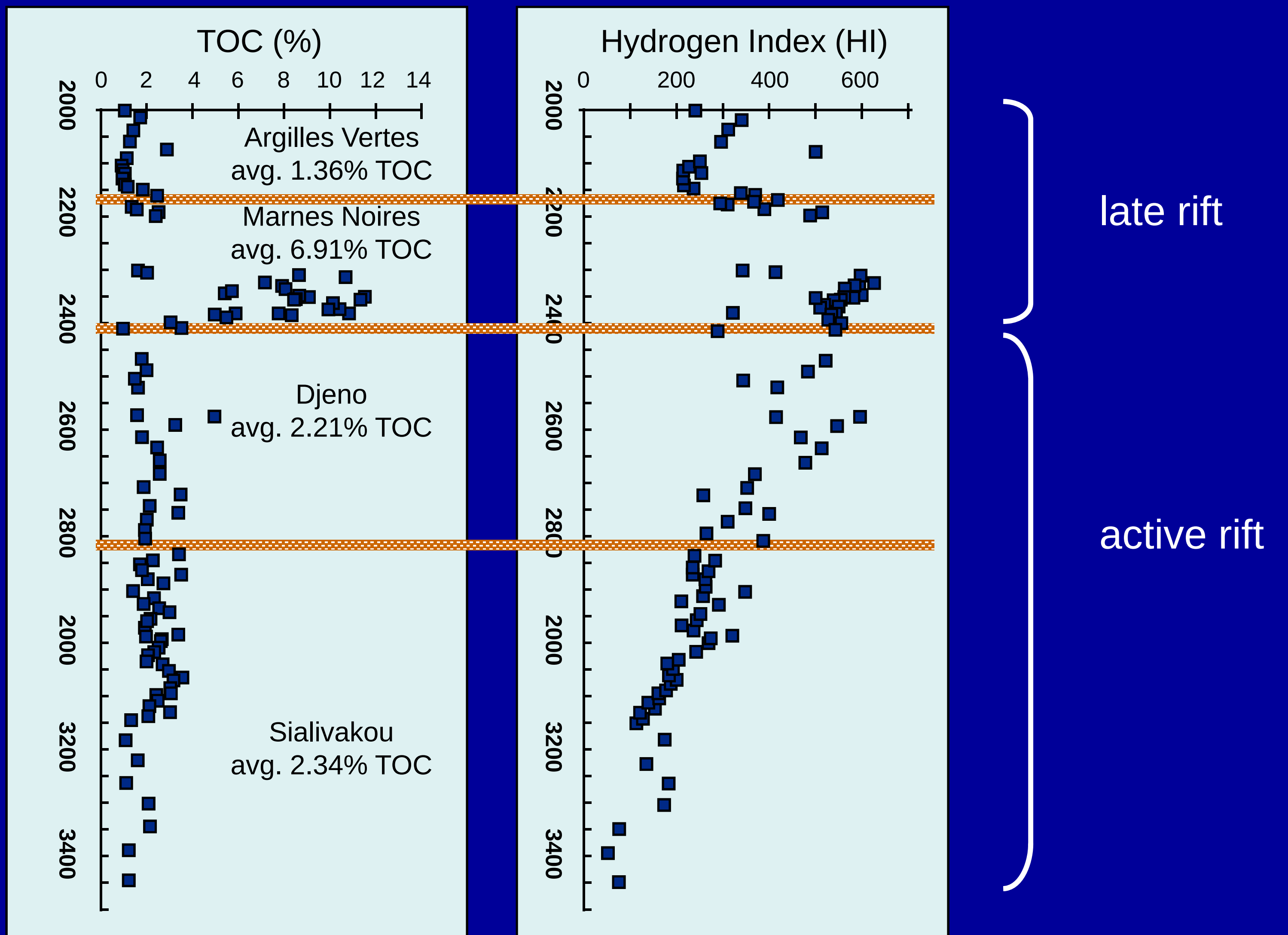


Late Rift

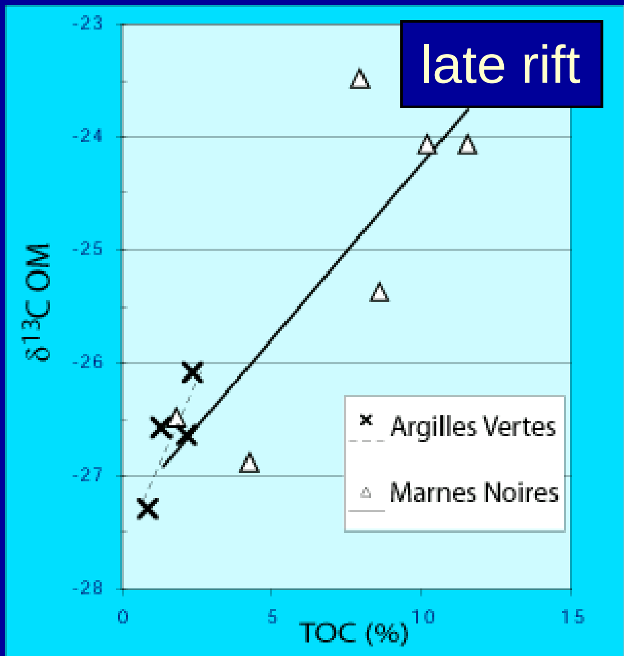
Subsidence < Sedimentation

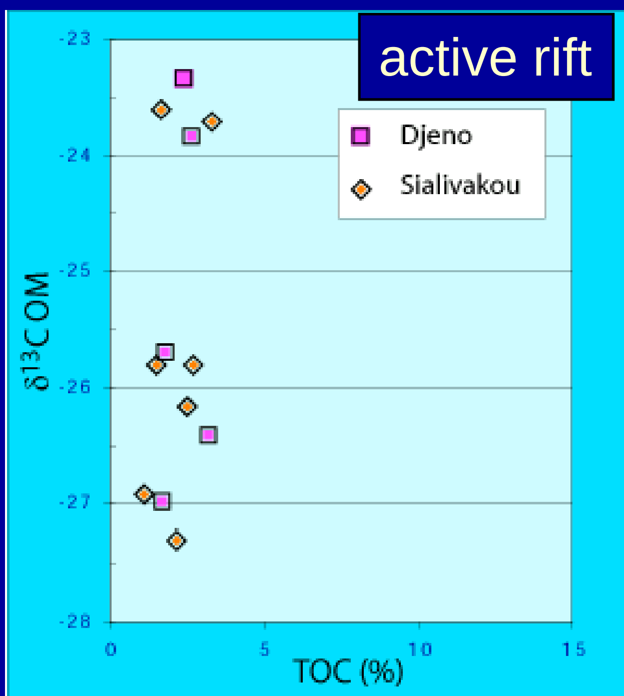


Congo Basin, West Africa



from Harris, 2004

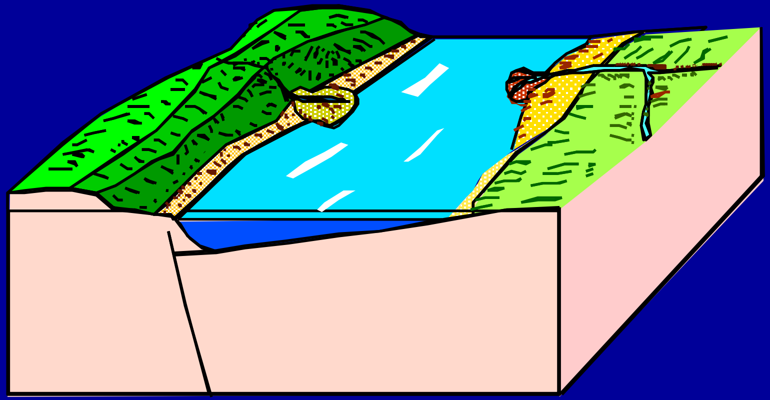




Positive correlation between total organic carbon and isotopic composition of organic matter in late rift

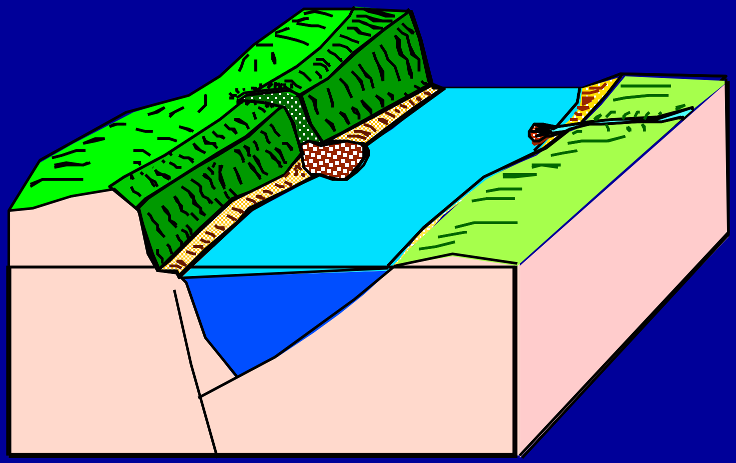
→ Transition from active rift to late rift is driven by increase in organic productivity and nutrient supply.

→ So how to account for the increase in nutrient supply?



Flatter slopes, thicker soils

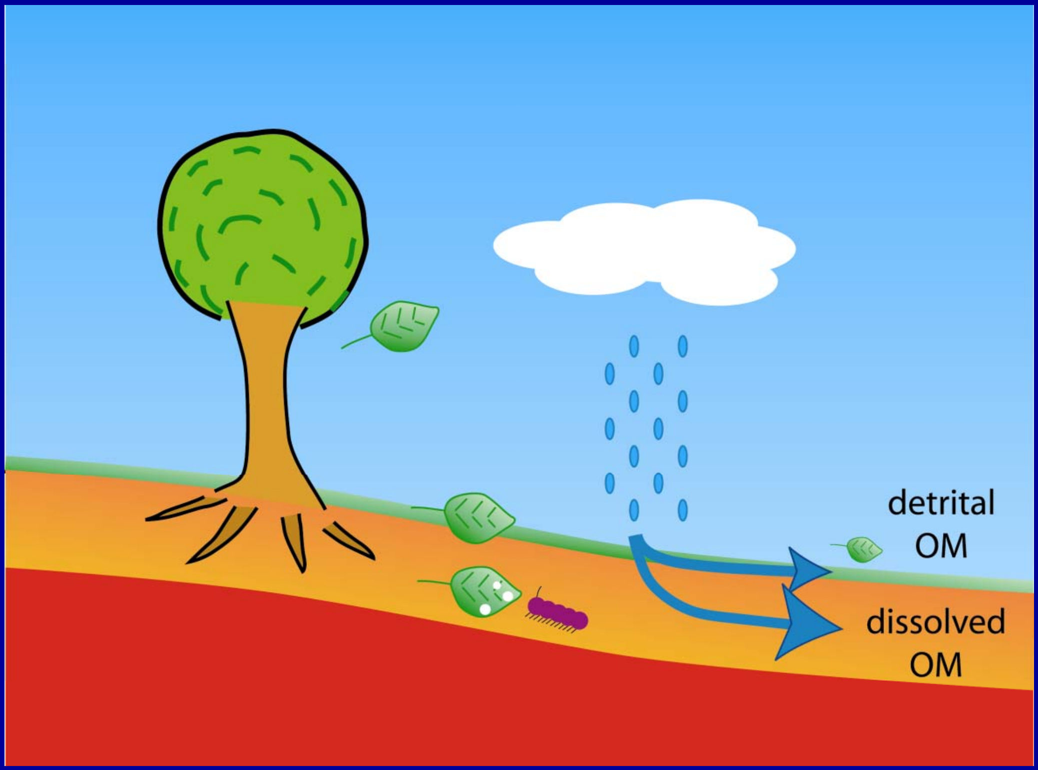
Late Rift



Steep slopes, thin soils

Active Rift Stage

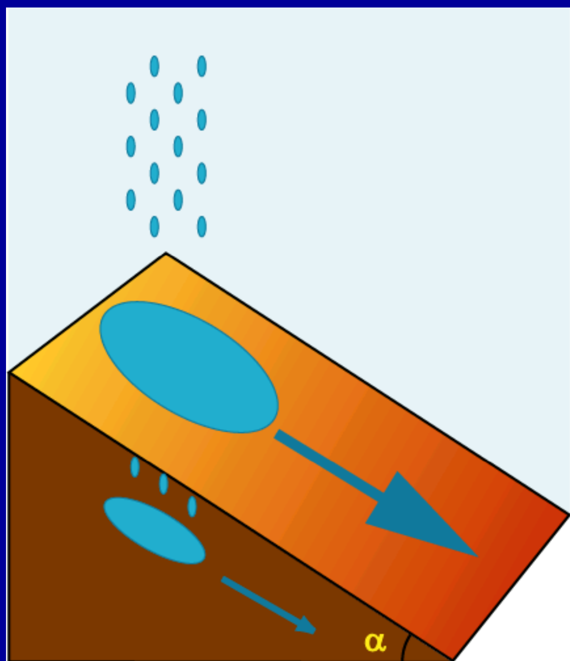
How does slope affect nutrient flux?

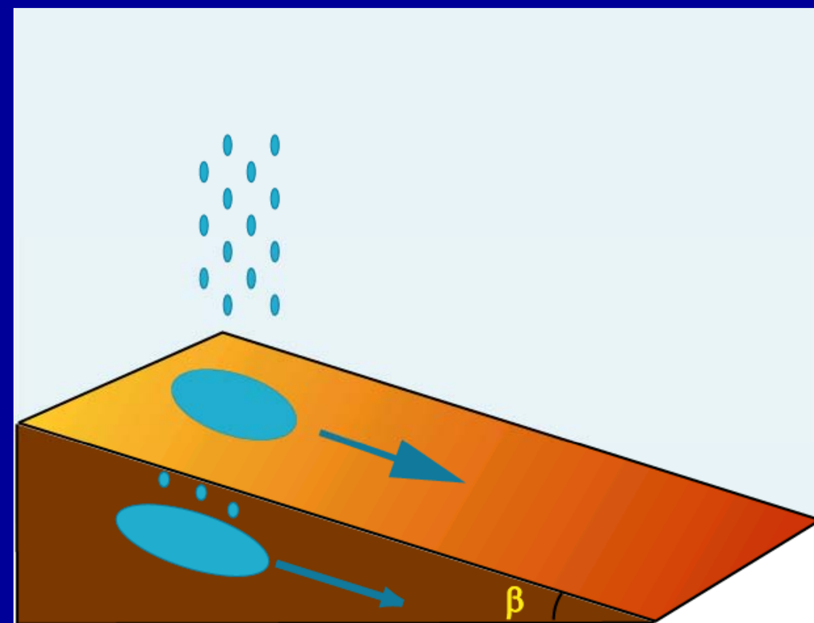


1) Steep slopes → more organic matter is eroded from the surface.

2) Flatter slopes → more organic matter incorporated into soil and transformed into dissolved nutrients

Impact of changing slope gradient on organic nutrients

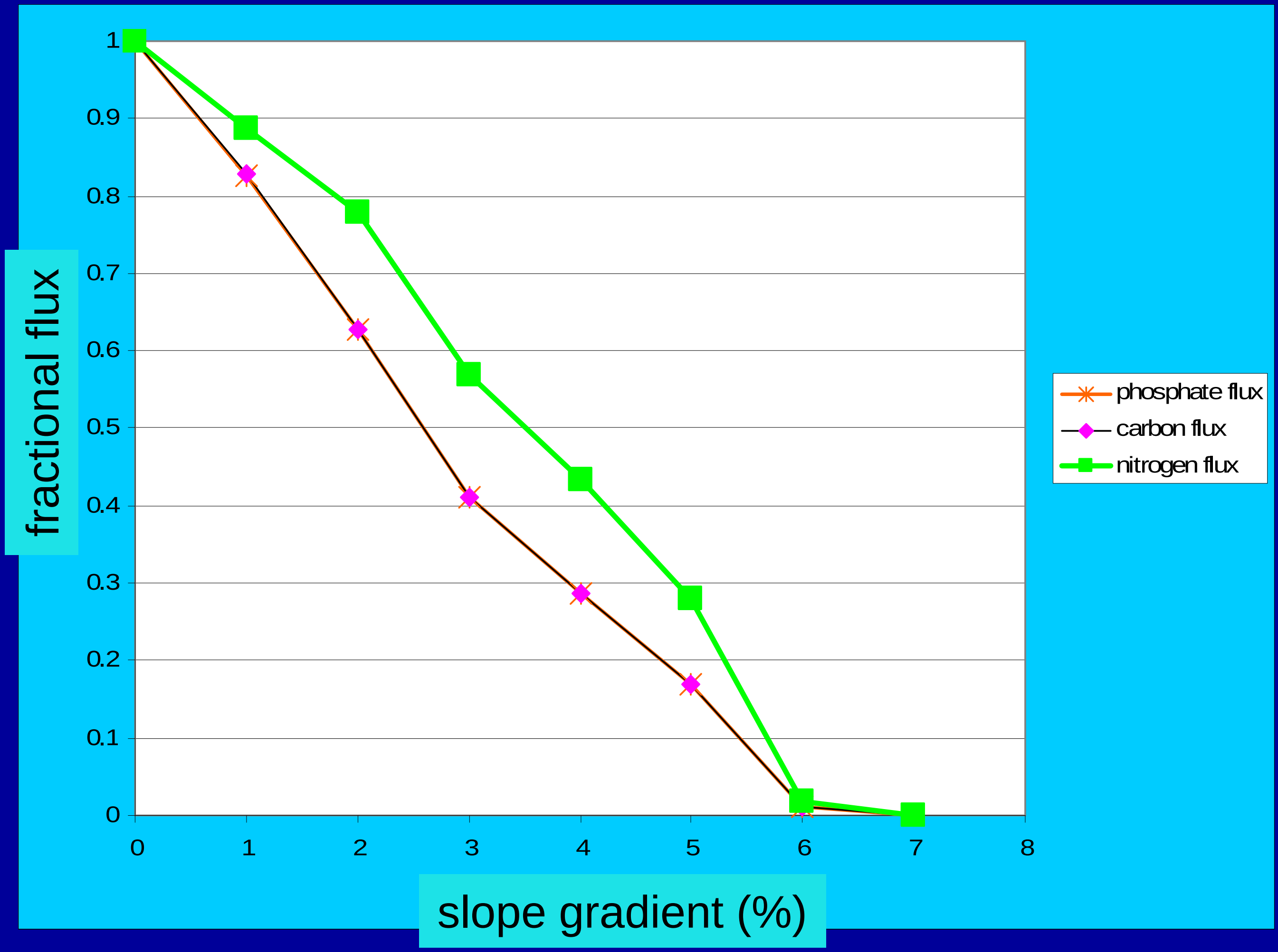




Runoff decreases

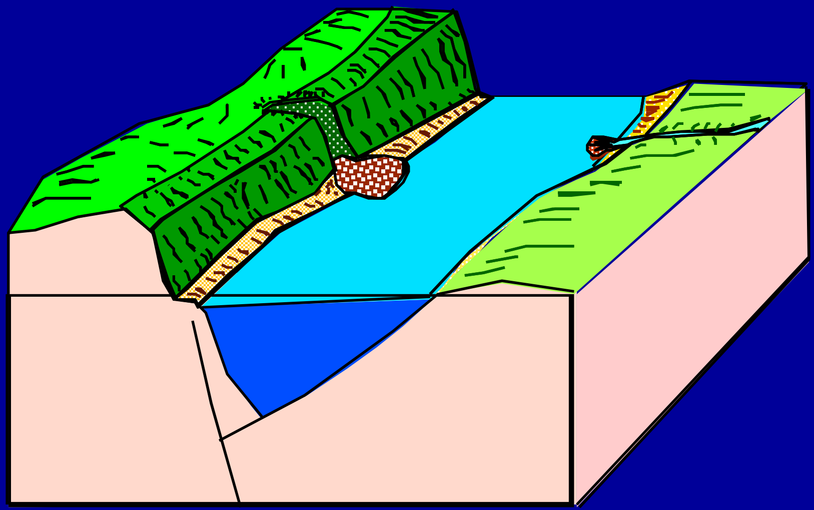
→

Infiltration increases

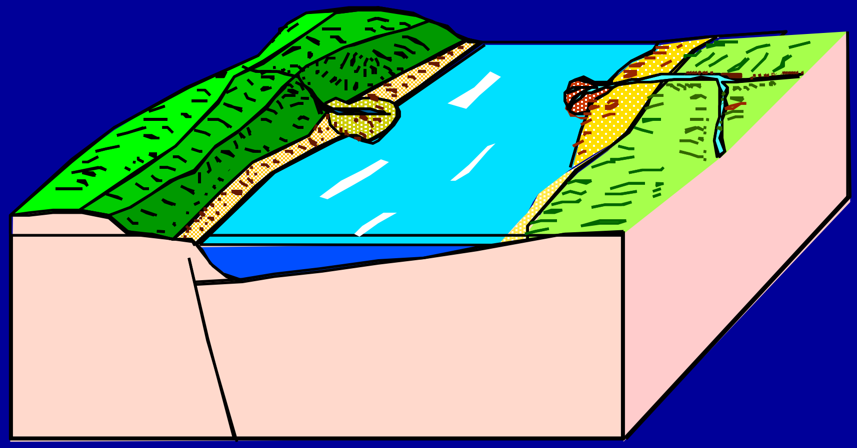


As slopes become flatter, the flux of nutrients increases

Active Rift Stage



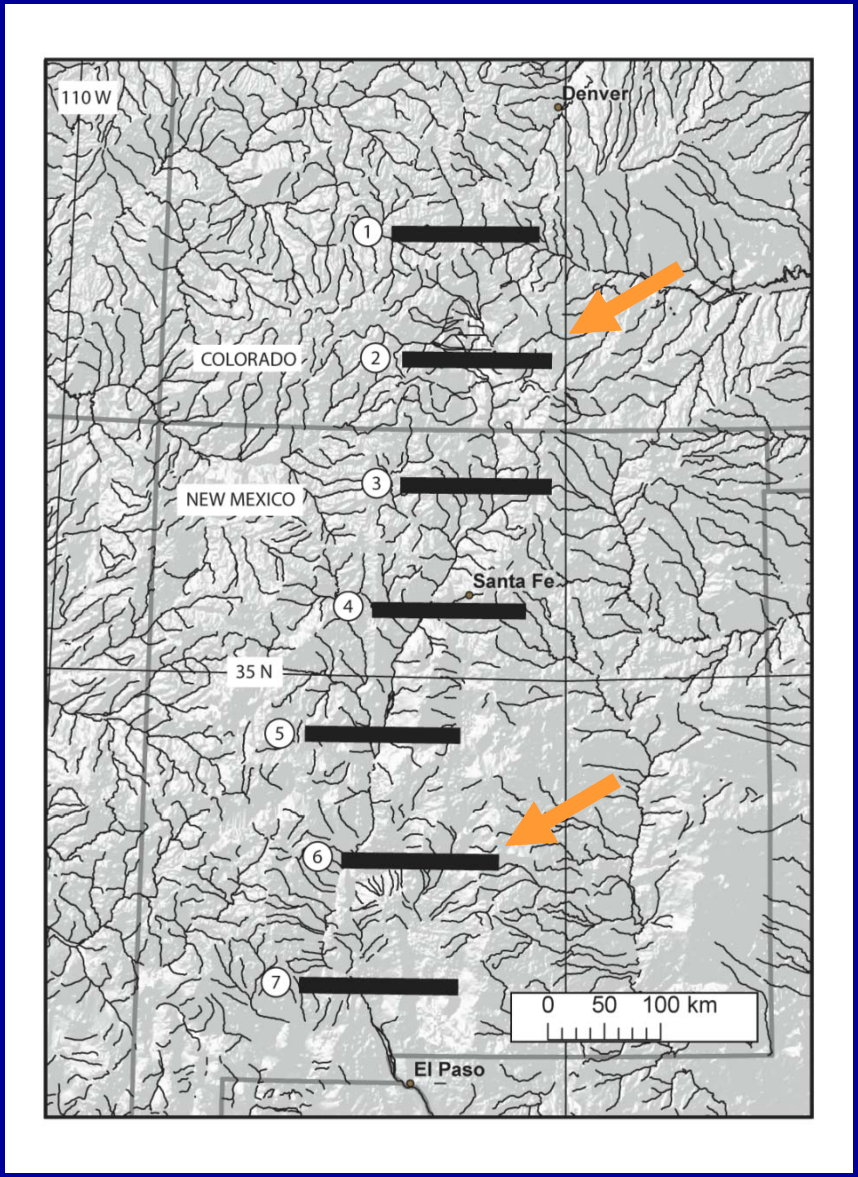
Late Rift

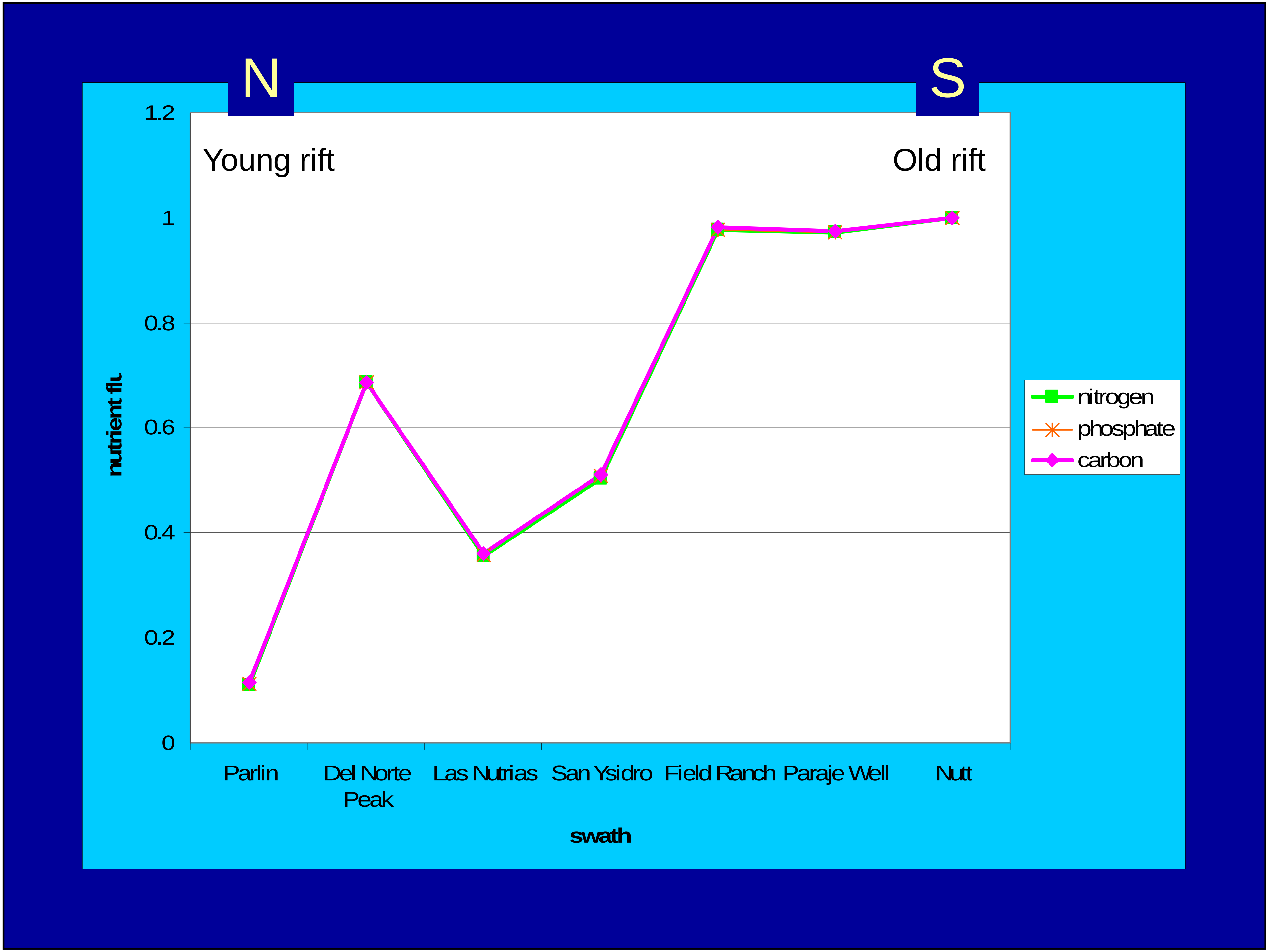


So … what might be the consequences in a real rift?

Look at the Rio Grande Rift system.

Rio Grande Rift, southern Colorado and New Mexico




N
S
Young rift
Old rift
1.2
1
0.8
0.6
0.4
0.2
0
nutrient flu
Parlin
Del Norte Peak
Las Nutrias
San Ysidro
Field Ranch
Paraje Well
Nutt
swath
nitrogen
phosphate
carbon

What have we learned ?

Climate alone can have a great effect on nutrient delivery

Slope gradient affects infiltration of rainfall

→ organic productivity

→ nutrient delivery

Slope gradient affects partitioning dead vegetation between soil and erosion

Selected References

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