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Modeling Marine Carbon and Phosphorus Cycling During Cretaceous Oceanic Anoxic Events

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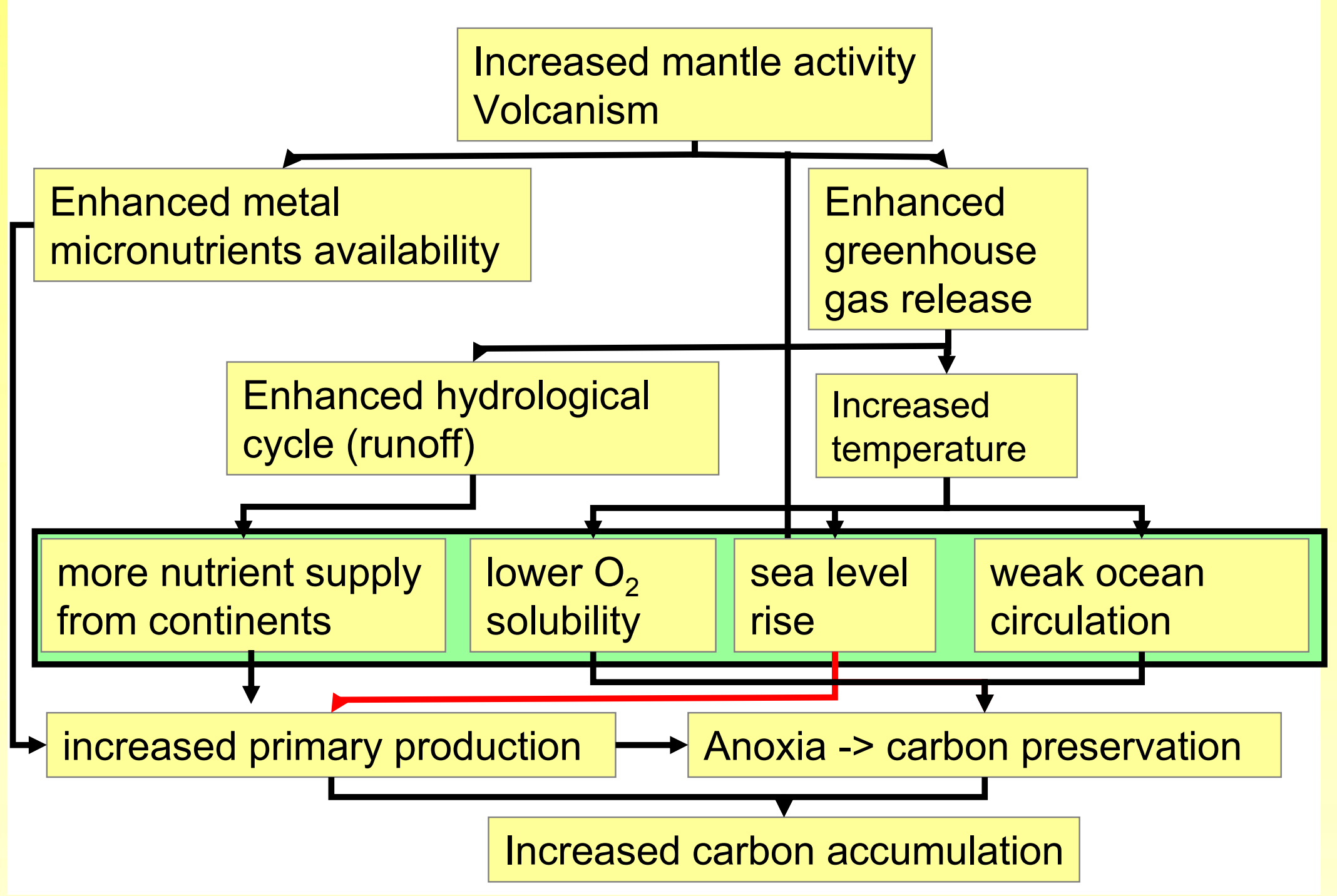
1. Introduction

Ocean anoxic events (OAEs) were periods of high carbon burial that led to lowering of bottom water oxygen concentrations and drawdown of carbon dioxide.

Oceanic anoxic events are thought to result from high productivity but the factors responsible for triggering and sustaining ocean anoxia remain uncertain. Fig. 1 outlines of possible environmental triggers of OAEs in the Cretaceous.


Increased mantle activity
Volcanism
Enhanced metal micronutrients availability
Enhanced greenhouse gas release
Enhanced hydrological cycle (runoff)
Increased temperature
more nutrient supply from continents
lower O_2 solubility
sea level rise
weak ocean circulation
increased primary production
Anoxia -> carbon preservation
Increased carbon accumulation

Modified after Erba (2004)

2. Hypothesis

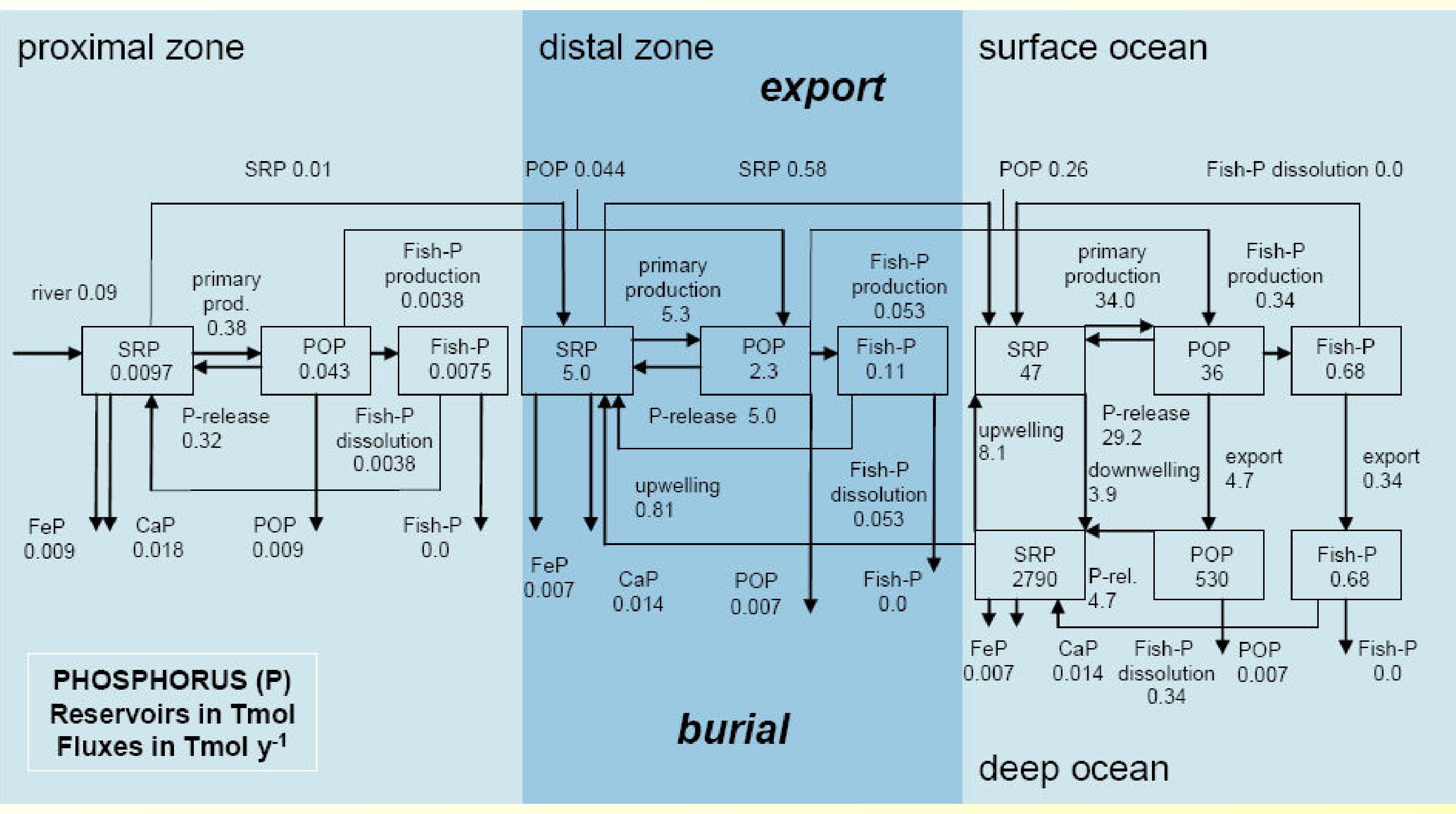
A boost in continental supply of phosphorus (P) to the ocean could have triggered enhanced primary production, oceanic anoxia and the formation of organic carbon (org C) rich deposits in both coastal and deep sea sediments in the Cretaceous. Enhanced P regeneration from the sediments helped sustain the anoxia but feedbacks in the ocean – atmosphere – land system ultimately led to it's termination.

3. Approach

Ocean Model Description

In this study, we use a modified version of an existing box model of the coupled oceanic cycles of phosphorus (P), organic carbon (org C) and oxygen (O_2) to assess whether we can explain typical C and P profiles observed in the geological record for the Cretaceous Oceanic Anoxic Event at the Cenomanian – Turonian boundary (OAE-2; ~94Myrs BP).

Fig. 2 – Steady state cycle of P in the model



Slomp and Van Cappellen (2007)
SRP = soluble reactive phosphorus, POP = particulate organic phosphorus, CaP = Ca-bound P

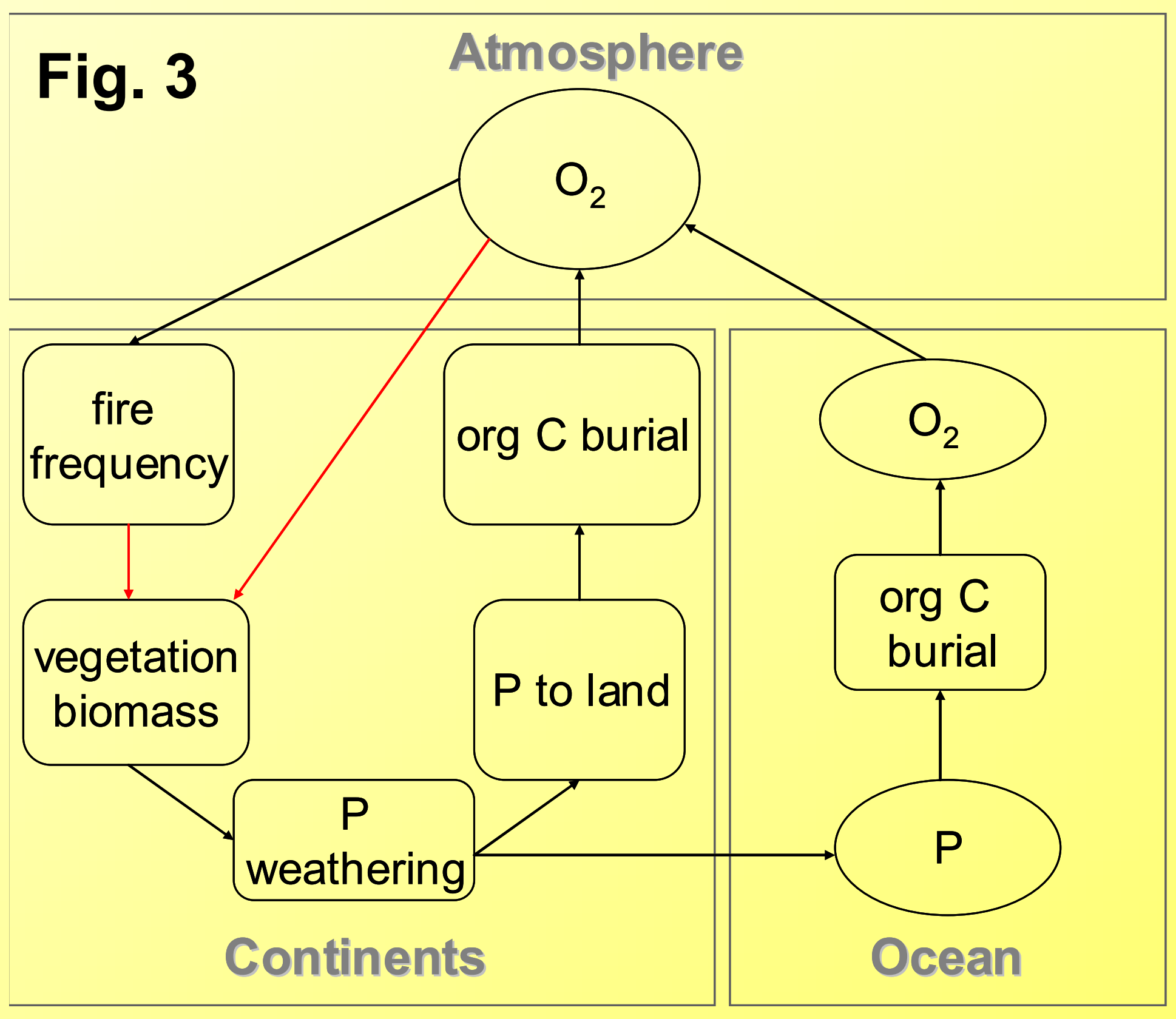
Atmospheric and Land Feedbacks

The model was extended to include an atmospheric O_2 cycle and redox-dependent P burial in the coastal ocean.

The atmospheric O_2 cycle feeds into the existing marine O_2 cycle, by equilibrating the surface ocean O_2 with the atmosphere.

Atmospheric oxygen is affected by org C burial in the ocean and on land (positive feedbacks), oxidative weathering (negative feedback) and forest fire frequency on land (negative feedback).

Fig. 3

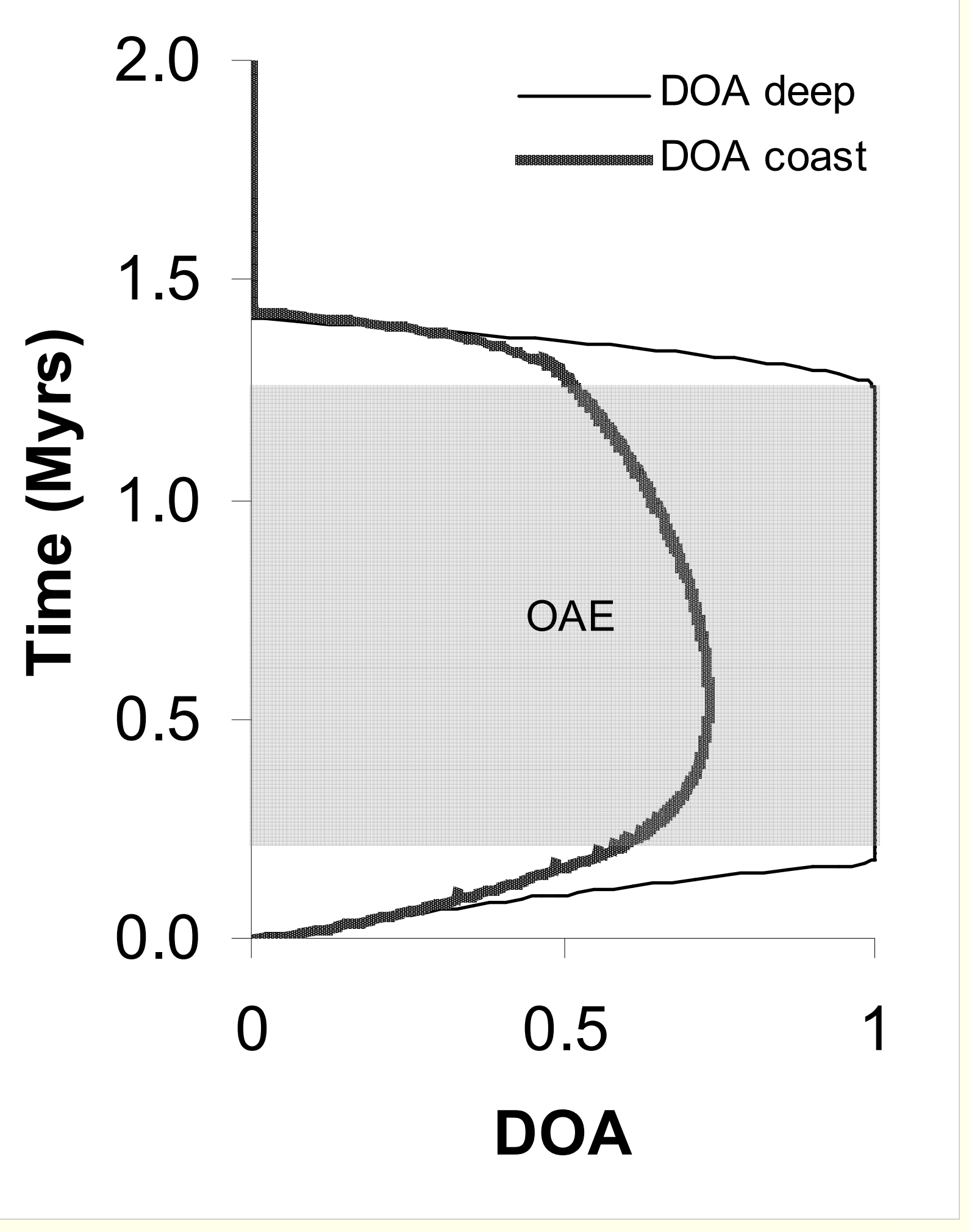

Atmosphere
O_2
fire frequency
org C burial
O_2
vegetation biomass
P to land
org C burial
P weathering
P
Continents
Ocean

Modified from Lenton and Watson (2000)

4 .Results

A steady state marine P and organic C cycle was perturbed by forcing the continental supply of weathered P to increase by 30% at time t = 0

Fig. 4: Degree Of Anoxia



The increase of nutrient delivery causes a boost in primary production which depletes the oceanic O_2 reservoir, inducing partial anoxia in the coastal ocean and complete anoxia in the open ocean (fig. 4).

On the coast, where anoxia is incomplete, the P and org C burial increase due to a boost in primary production (fig. 5).

Fig. 5: C and P burial coast

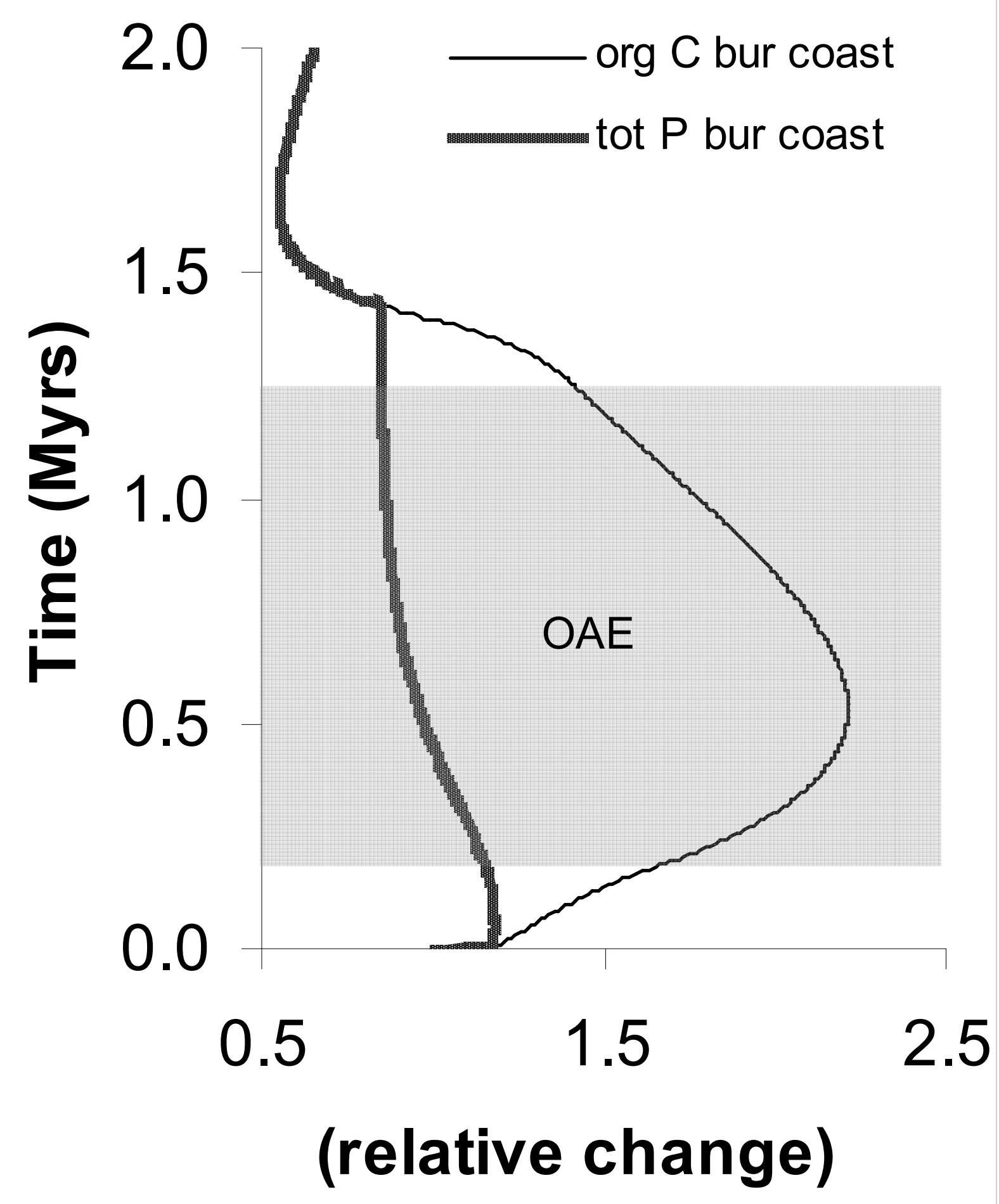
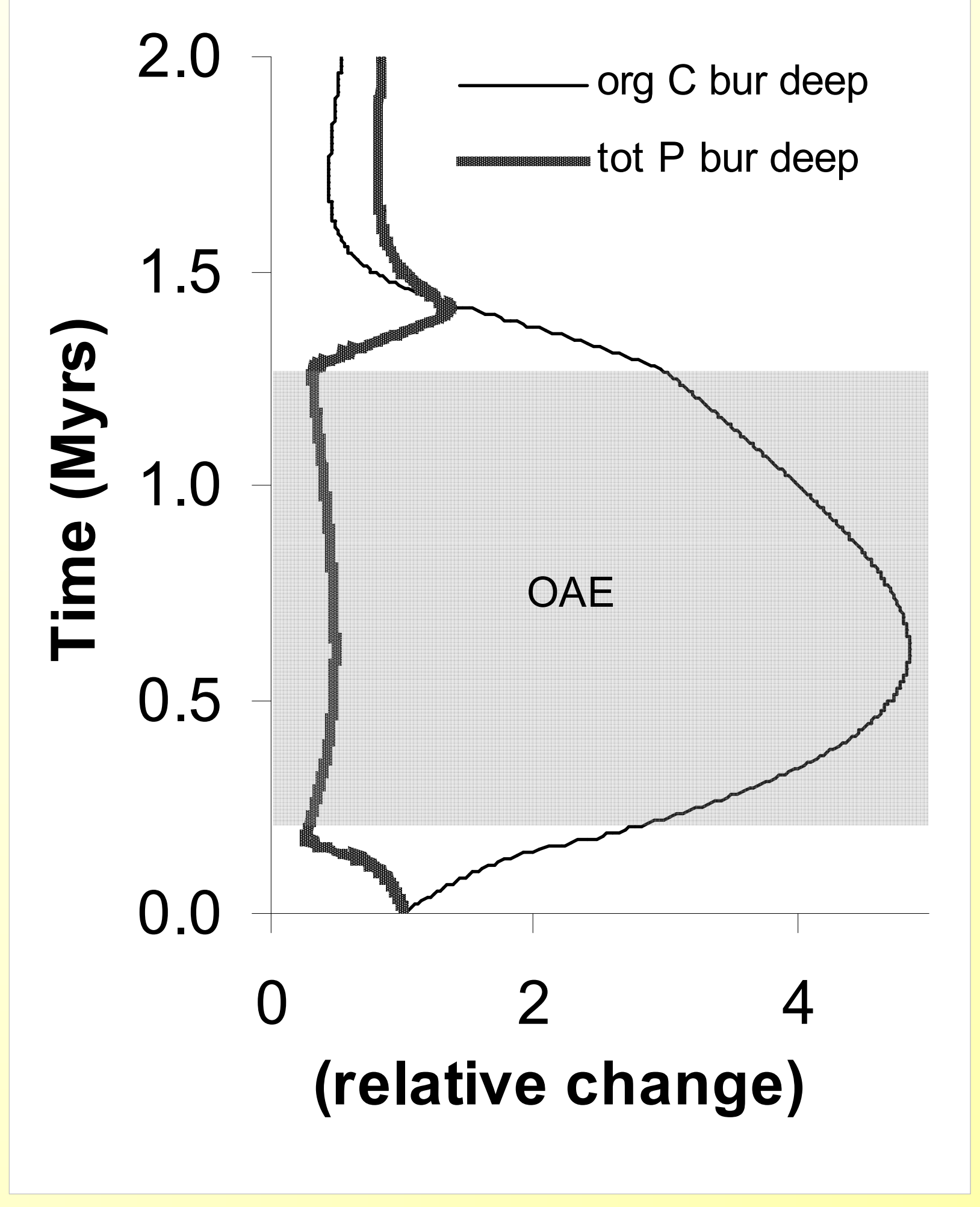


Fig. 6: C and P burial open ocean



In the deep sea, where anoxia is complete, org C and P follow anti-parallel burial trends (fig. 6). This is because, under low O_2 conditions, org C is preserved while P is regenerated. This has the effect of fueling further primary production and respiration of organic matter in ocean waters, thus sustaining ocean anoxia.

Anoxia is finally terminated due to a rise in atmospheric oxygen (not shown) that helps re-ventilate deep ocean waters and allows burial of P to increase (fig. 6).

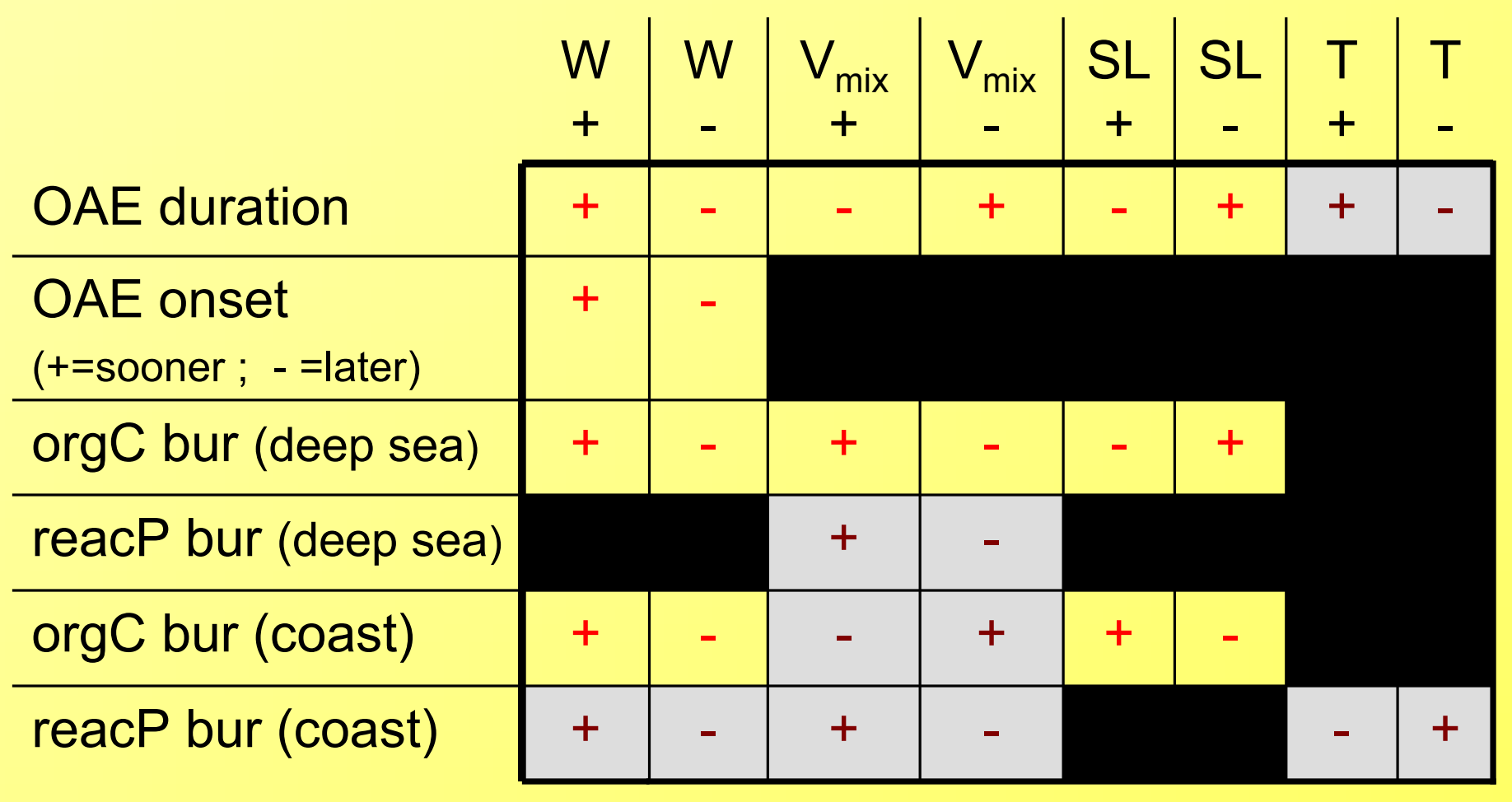
Sensitivity analysis

Oceanic anoxic events are a robust response to a weathering pulse from the continents, given that some conditions are satisfied:

Necessary factors for ocean anoxia:
- Slow surface – deep water exchange
- P recycling from sediments under dysoxic conditions

Necessary factors for black shales:
- Org C preservation under dysoxic conditions necessary for "black shales"

Fig. 7: Summary of sensitivity analysis



	W +	W -	V_{mix} +	V_{mix} -	SL +	SL -	T +	T -
OAE duration	+	-	-	+	-	+	+	-
OAE onset (+=sooner ; - =later)	+	-	■	■	■	■	■	■
orgC bur (deep sea)	+	-	+	-	-	+	■	■
reacP bur (deep sea)	■	■	+	-	■	■	■	■
orgC bur (coast)	+	-	-	+	+	-	■	■
reacP bur (coast)	+	-	+	-	■	■	-	+

Legend: + = positive effect
- = negative effect
black shade = negligible effect
grey shade = small effect

W = weathering pulse strength
V_{mix}= mixing intensity
SL = sea level
T = temperature

Most influential forcings: V_{mix} and W (Fig. 7)

Non-influential forcing: temperature.

5. Conclusions

- Typical trends in total P (and org C) burial for OAEs can be produced with a global model of the oceanic C, P and O_2 cycles.
- We confirm that, given some necessary initial conditions and internal mechanisms, a moderate weathering boom can consistently trigger ocean anoxia
- OAEs can be sustained by P recycling from sediments. A feedback of atmospheric O_2 on P recycling leads to the termination of the OAE
- The degree of anoxia defines the nature of the burial record … shelf burial differs from deep sea burial.
- OAEs lead to a further shift in P burial from the deep ocean to the coastal ocean.