IAEA CN-186
28 Mar – 1 Apr 2011
Monaco

Workshop 1: Isotopes in Marine Climate Studies

REGIONAL CONTROLS ON HOLOCENE SEDIMENTATION PATTERNS ALONG THE PERU CONTINENTAL MARGIN; LONG TERM IMPLICATIONS FOR EL NIÑO-SOUTHERN OSCILLATION

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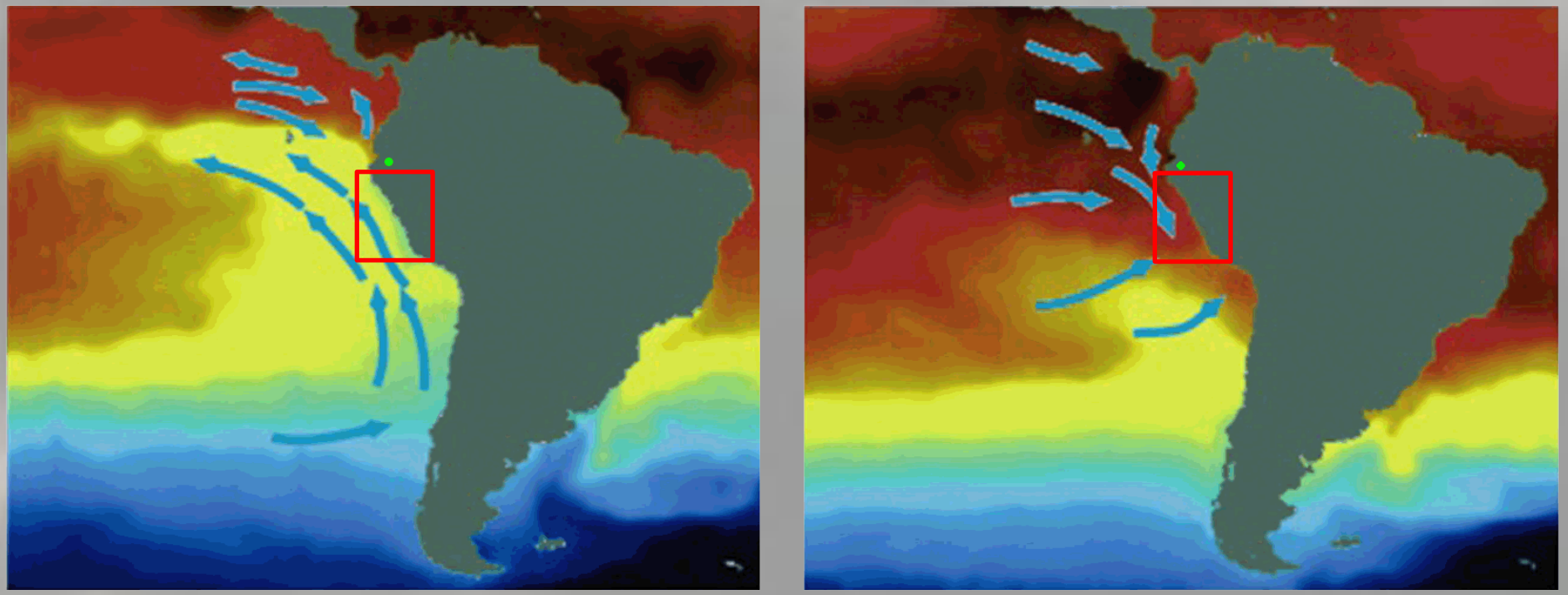
El Niño-Southern Oscillation (ENSO)

"Normal" or La Nina conditions

El Nino conditions



water temperature °C

<0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30>

Outline

- Where is our understanding now?
- "New" data
  - Radiocarbon re-calibration
  - Pattern of sediment accumulation
  - Geochemical evidence
- Oceanographic implications

Is this (interannual) ENSO?

The GUIDELINE

- Modern (instrumental) ENSO recurrence 2 – 7 years over ~130 years with modal frequency ~5+ yr

The EVIDENCE

- **Geochemistry** (multiproxy, consistent, but incomplete time series)
- **Image Analysis** (resolution 0.1 mm per pixel; interannual aliasing precluded, pixels per year?)
- **Layer Counting** (subjective, independent of image analysis)

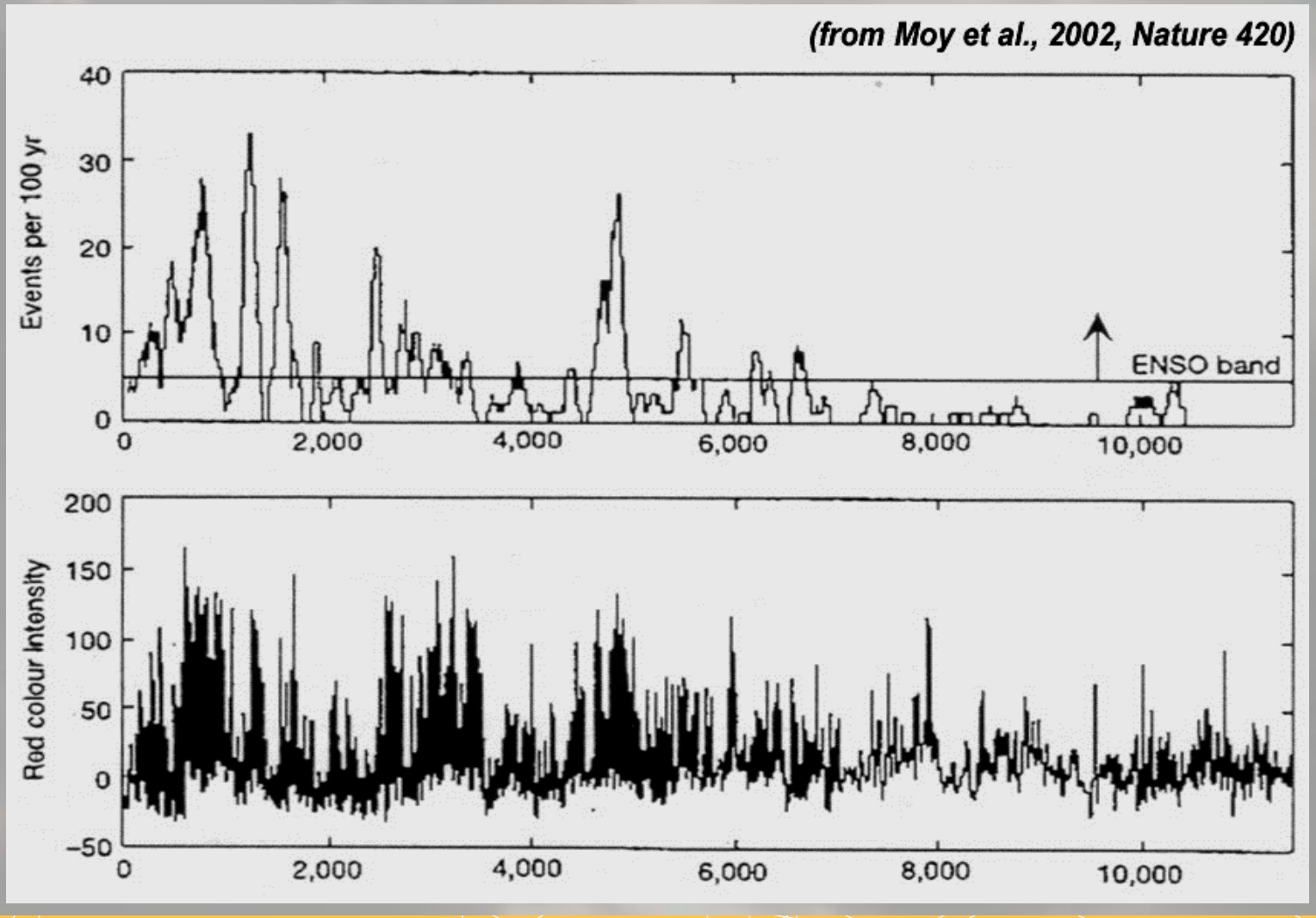
Palaeo – ENSO: Previous work

What is the problem?

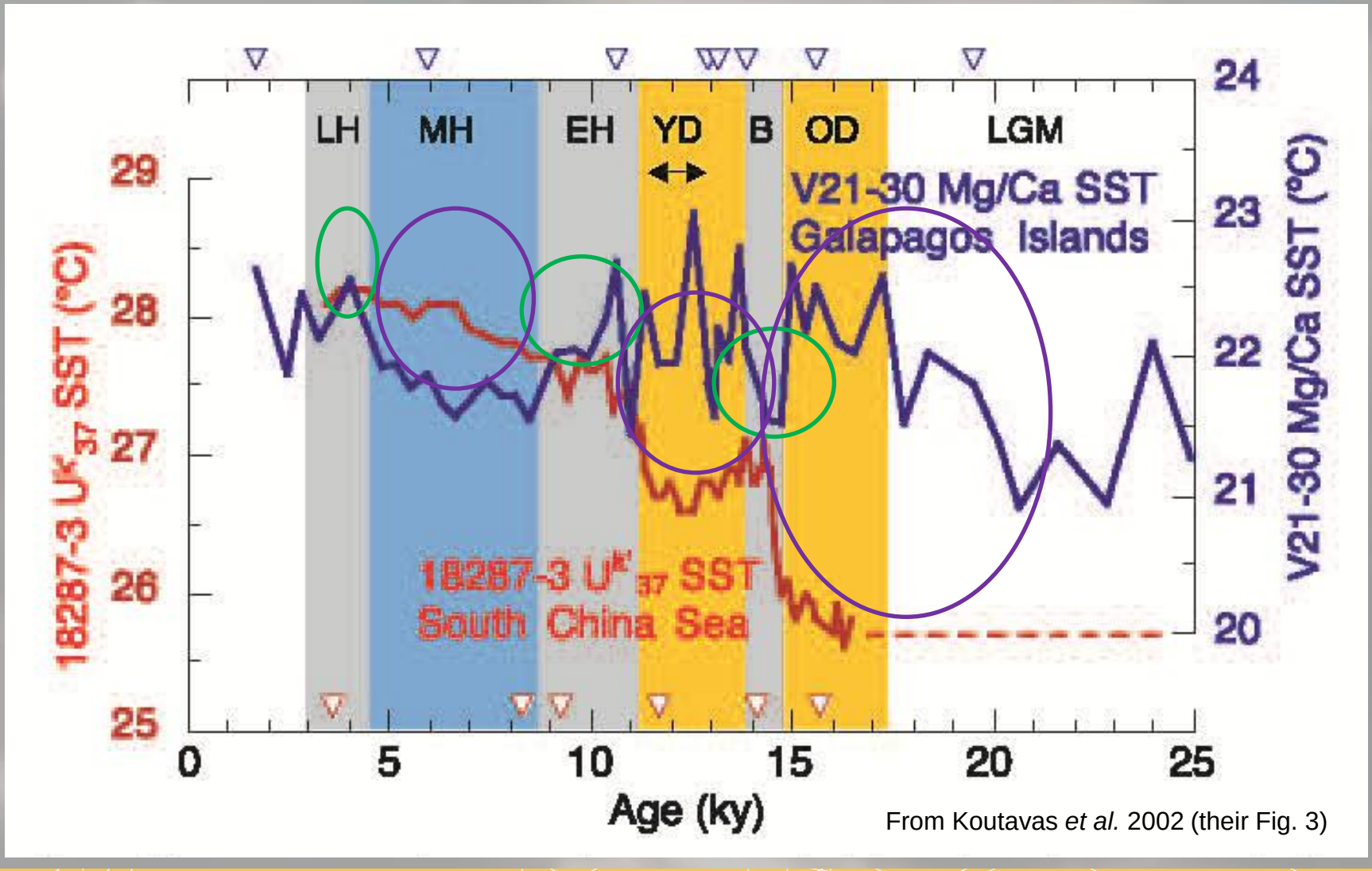
ENSO reduced or absent between 15ka and 6ka

- **Sandweiss *et al.* 1996a & b;** between 5800 and 3200-2800 Cal yr BP, El Nino events less frequent that today, and for several millennia prior to 5800 yr El Nino "absent or very different from today" (archaeological, molluscs) (8°S – 18°S) (*Geology, Nature*)
- **Koutavas *et al.*, 2002;** 30,000 yr low-resolution magnesium-calcium ratio in foraminifera near Galapagos Is compared with west Pacific alkenone SST record show "mid-Holocene cooling" suggestive of La Nina conditions; late mid and early Holocene, and 14-15 ka (Bølling) similar to today (*Science*)
- **Moy *et al.*, 2002;** Continuous 12,000 yr record from Lake Pallcacocha; not quite ENSO interannual resolution, but variance in red colour intensity record suggests low variance in the Early Holocene; either ENSO starts after 7,000 yr BP, or is weak in the Early Holocene (2°-3°S) (*Nature*)
- **Gagan et al. 2004;** Onset of ENSO periodicities at ~5000 yrBP, with a sudden increase in ENSO magnitude at ~ 3000 yrBP and maximum ~2300-1700 yr BP; precipitation response to El Nino temp anomalies "subdued" in mid Holocene; western-central Pacific; attributed to mean southward shift in the ITCZ [*Quaternary International*]

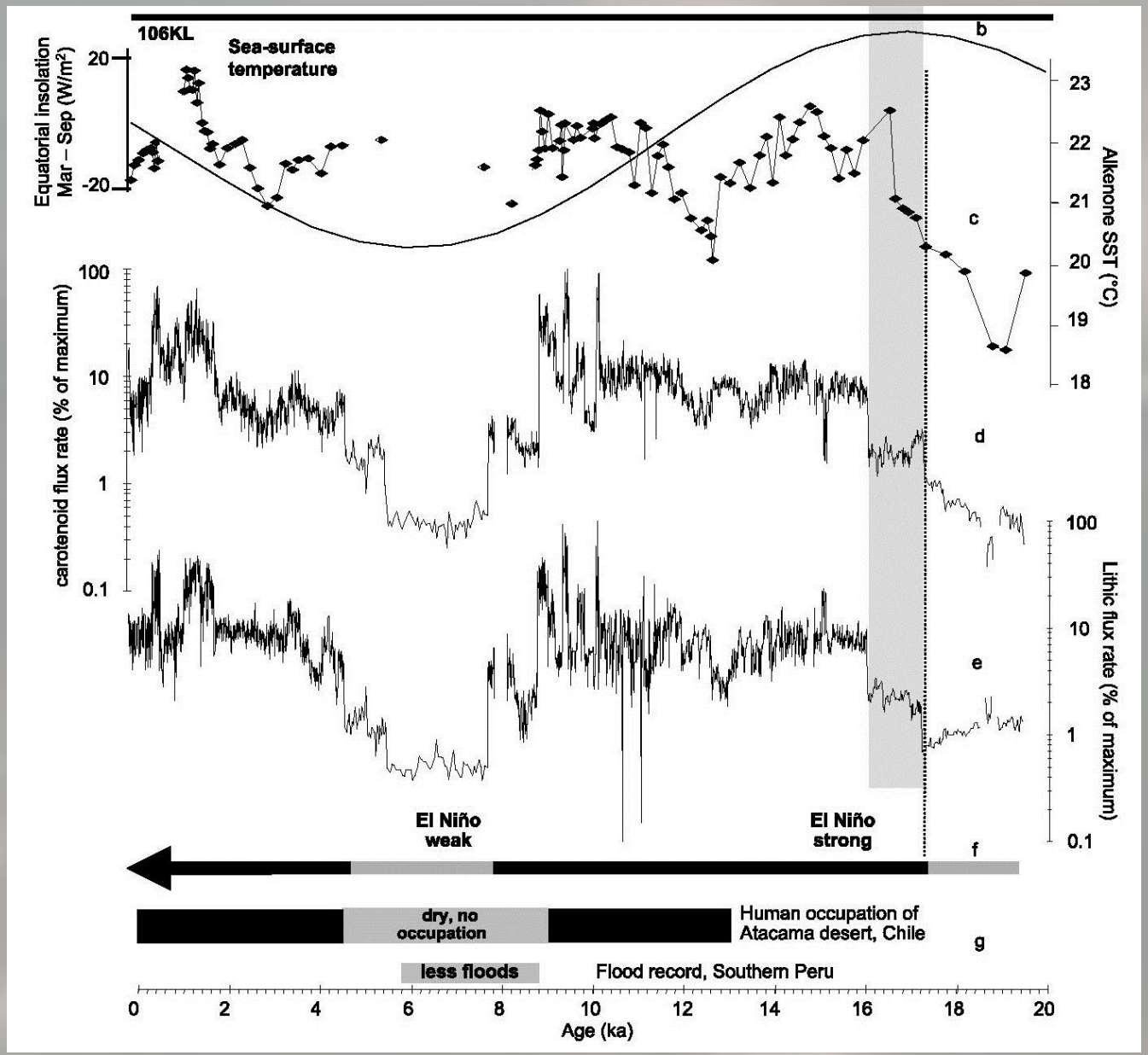
Eastern Pacific Holocene Record



Tropical Pacific SST Gradient



From Koutavas *et al.* 2002 (their Fig. 3)



Rein et al. 2005; SST ~ 2°C warmer than today between 10,300 and 8,900 yr BP; El Nino declining over last 800 yrs; Alkenone SST data; primary productivity index and terrestrial proxy for ENSO flooding since LGM; [*Paleoceanography*]

from Rein *et al.* 2005 (their Fig. 11)

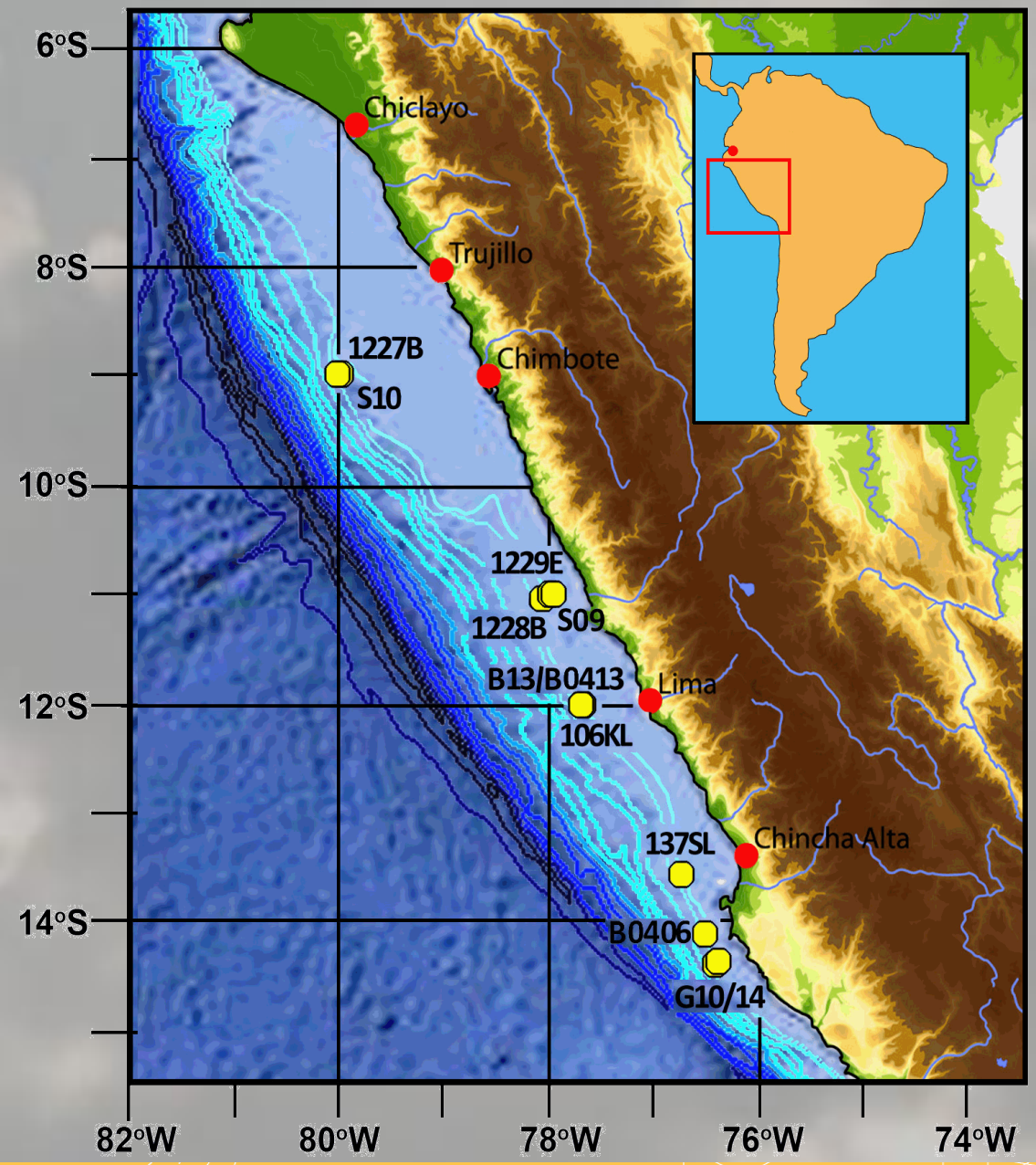
Summary

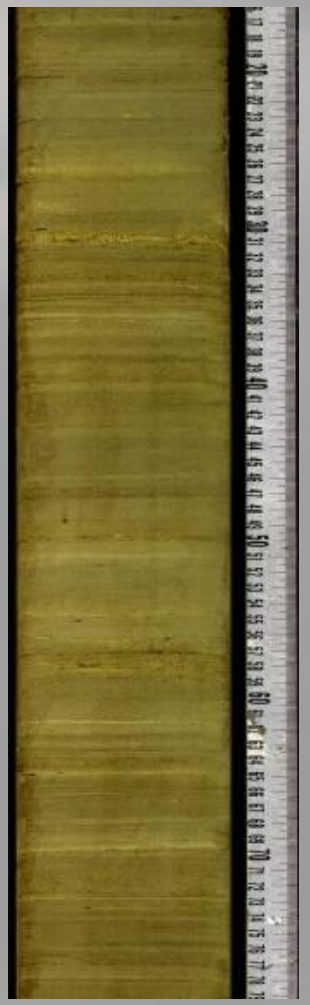
- Modern ENSO pattern continuous since post mid Holocene
- Tropical Pacific SST gradient greater in middle Holocene than currently
- Records not consistent for Early Holocene or LGIT
- Gaps?
  What happens to the currents and sediment in El Nino heartland during these periods?

"New" data

- Recalibrated and regionally extensive radiocarbon data
- Regionally consistent pattern of sediment accumulation
- High-resolution geochemical and image data

Location & Material





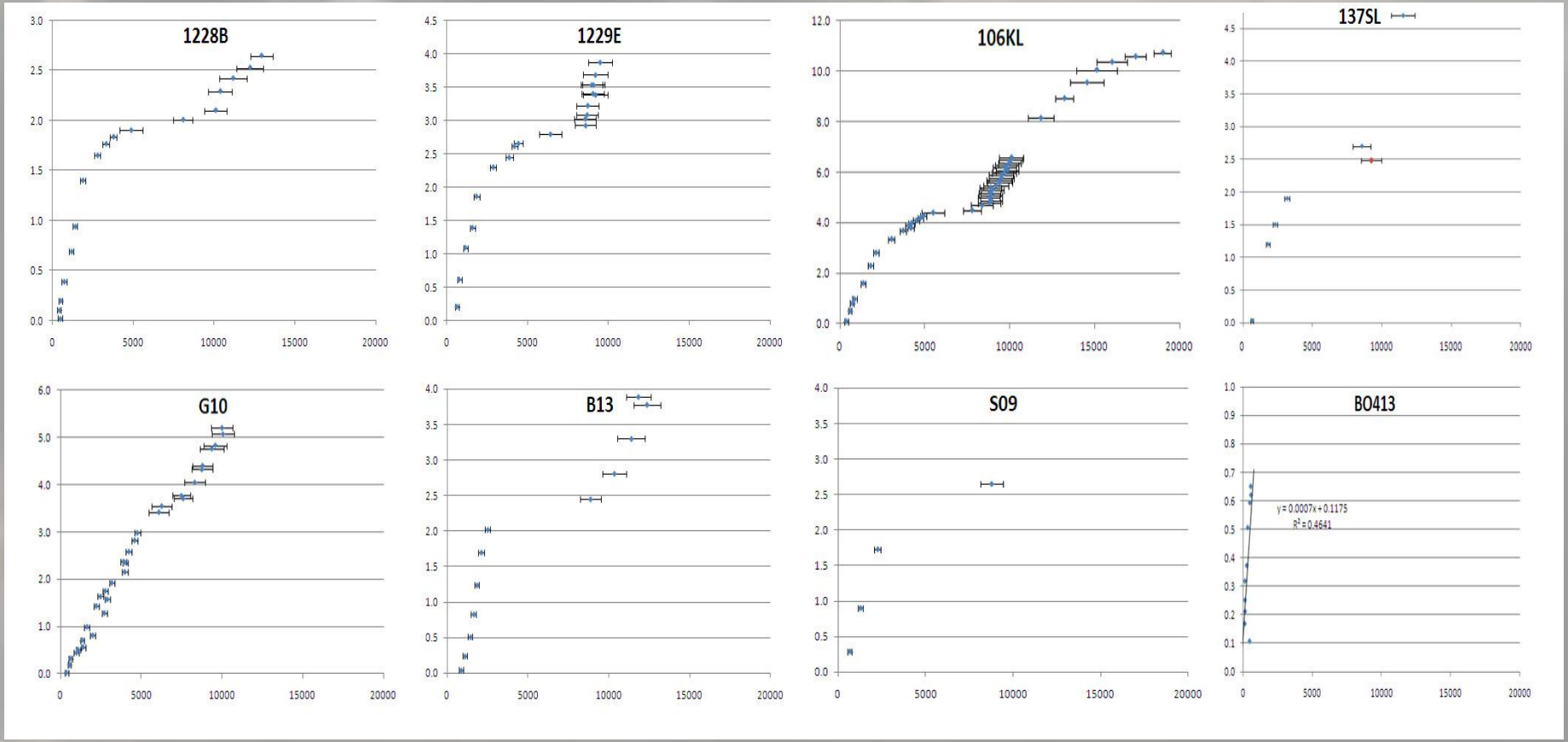
Regional Marine Reservoir Correction

Ortleib et al., 2010: [*Quaternary Research*]

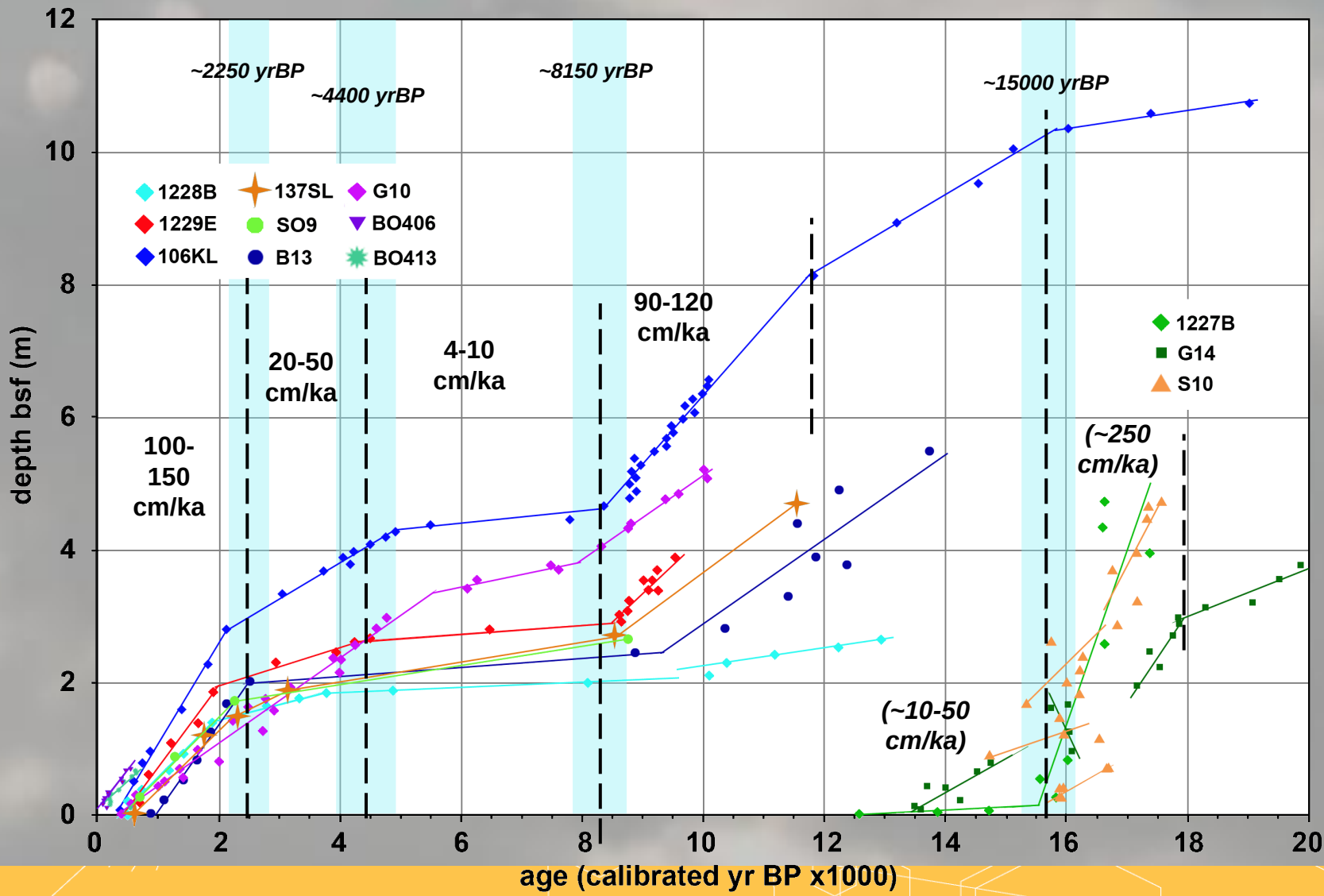
- On basis of co-located terrestrial (charcoal) and marine (shells) radiocarbon along Chilean coast determined extensive variability in regional marine reservoir effect ΔR
- 2σ range between 1000 – 500 yr but three-fold subdivision of Holocene:
  - **511± 278 yr** (10,500-6,800 yr BP)
  - **226± 98 yr** (5,200-1,000 yr BP)
  - **250-350** yr (<1000 yr BP)
- Inferred significant changes in ocean currents particularly with **old** carbon source (i.e. upwelling) reduced after 5000 yrs (i.e. long-term El Nino-like conditions increasing after 5500 – 5300 yr BP)
- **We have recalibrated all previously published radiocarbon ages using ΔR :**
  - **511± 278 yr (for > 5000 yr)**
  - **279 53 (for 0-5000 yr)**

  and the Marine09.14C Reimer et al. (2009) *Radiocarbon* 51

Holocene Age-Depth



Regional Pattern of Sedimentation

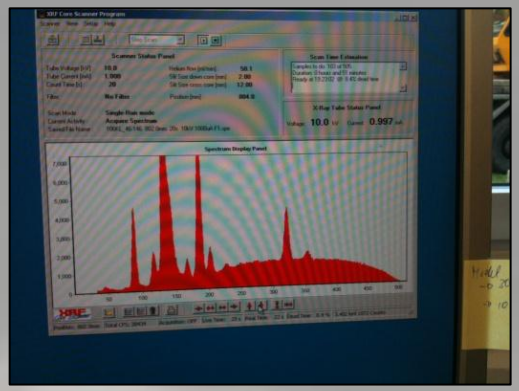


Changes in Sedimentation Rate?

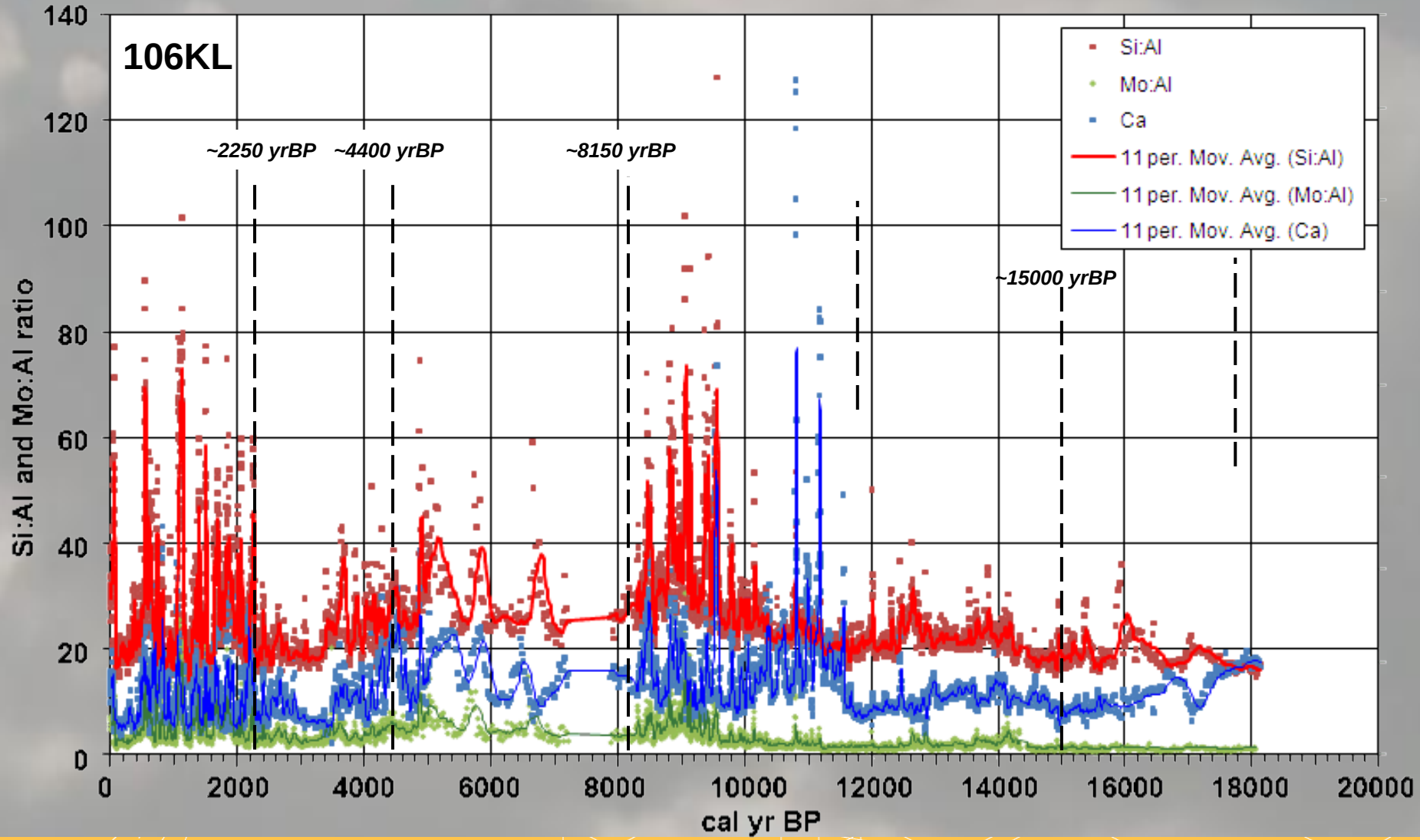
- The Record:
  - Sediment bypass
  - Deposition and Erosion
  - Changes to volume of sediment delivery
- Mechanisms
  - Ocean current velocity/direction *(strong upwelling in middle Holocene)*
  - Productivity/Nutrient load
  - Terrestrial input

XRF Scanning Data

- **Avaatech XRF Core Scanner**
- **106KL** *(Marum Bremen)*; **1229E, 1227A** *(College Station)*
- **Nineteen elements @ 2 mm interval**
  - **Al Si P S Cl K Ca Ti Mn Fe Rh**
  - **Cu Zn Br Rb Sr Zr Mo Pb**



Si:Al, Mo:Al, Ca Trends

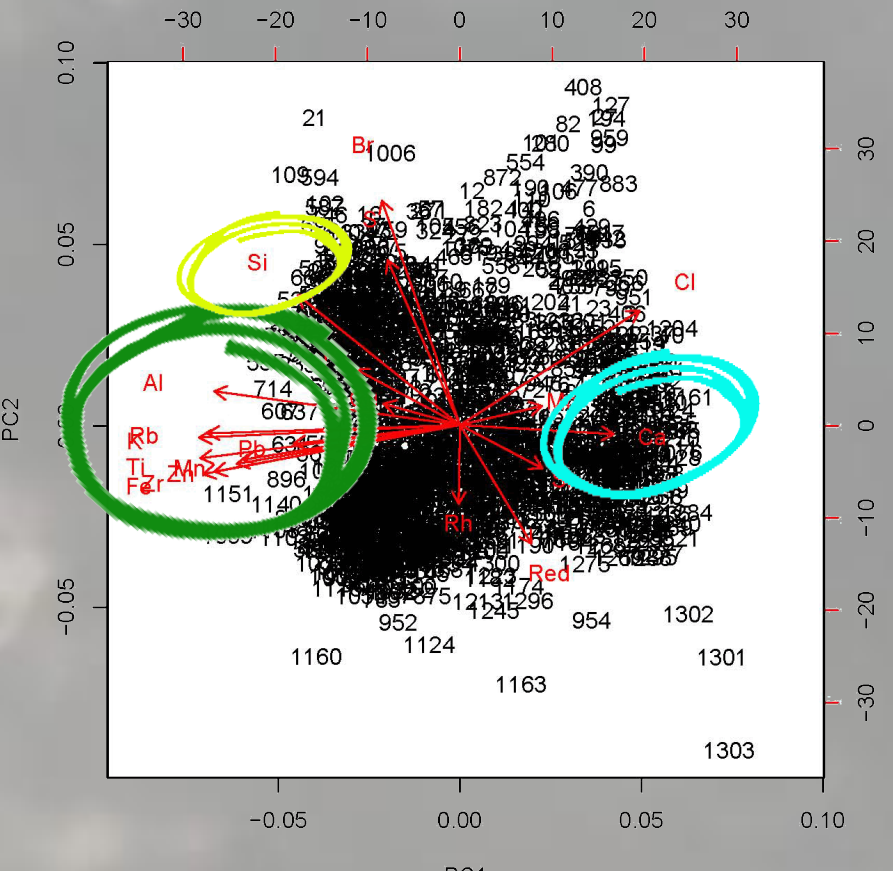


Statistics

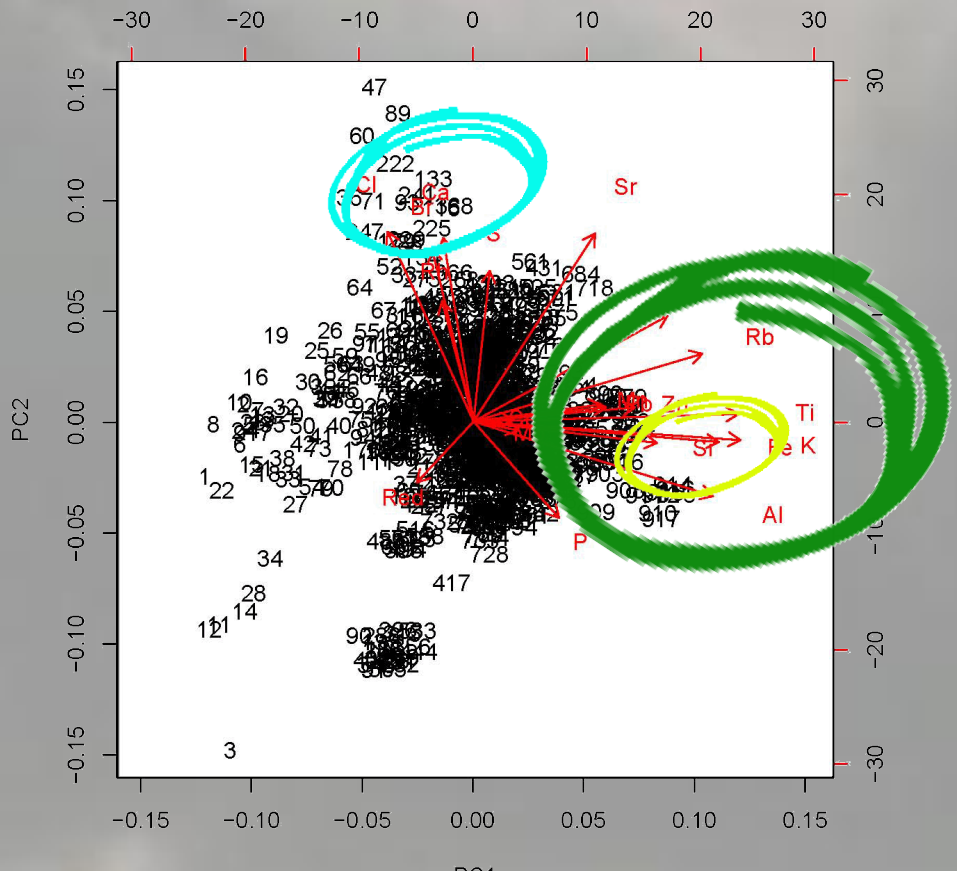
silicon

calcium

Terrestrial group



106KL late Holocene



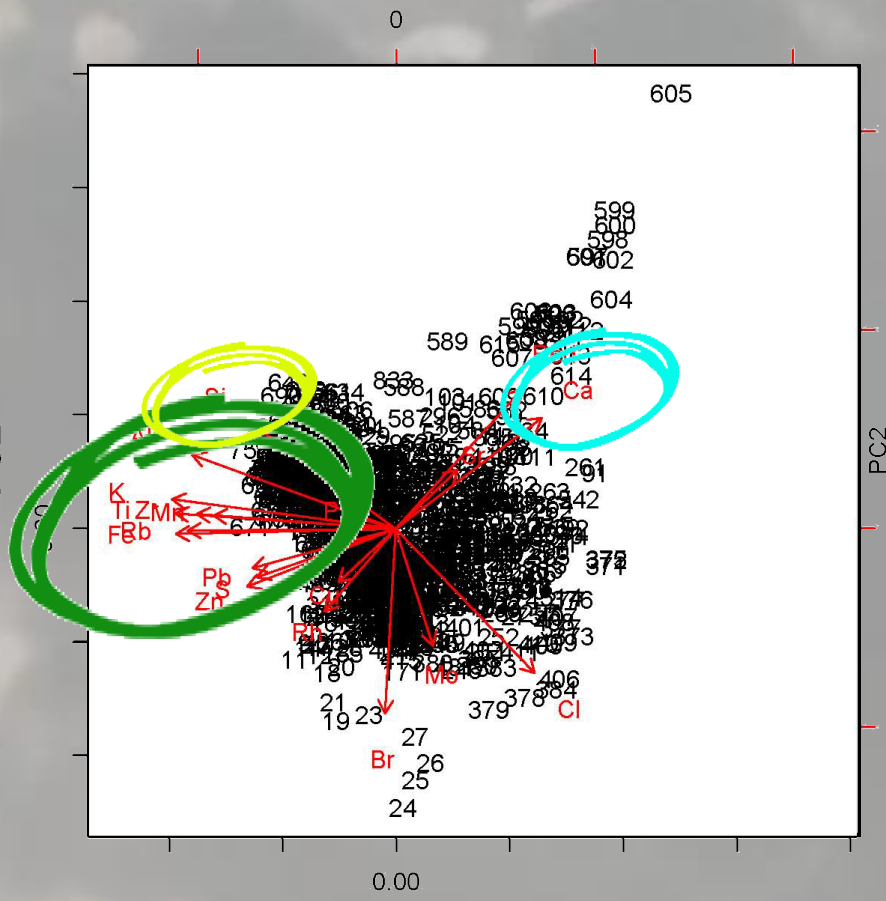
1229E late Holocene

Statistics (cont)

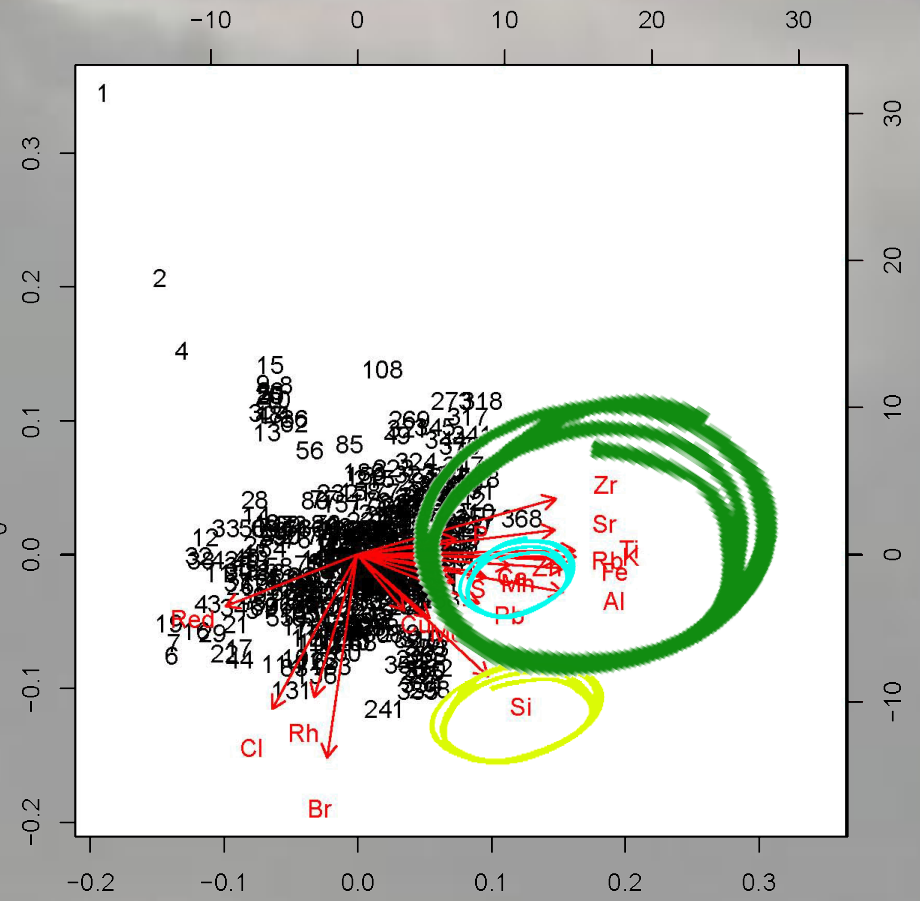
silicon

calcium

Terrestrial group

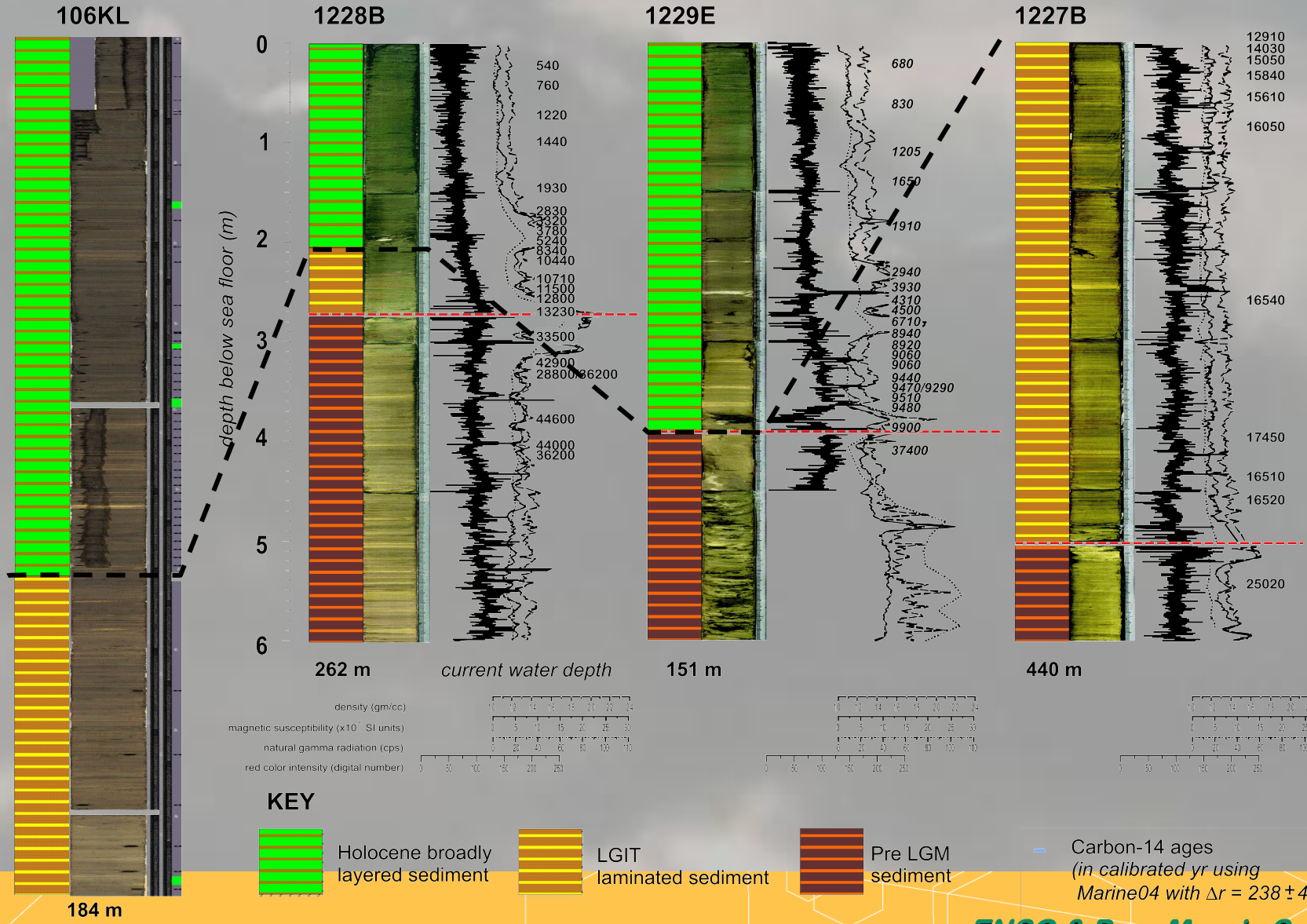


106KL early Holocene



1229E early Holocene

Stratigraphy



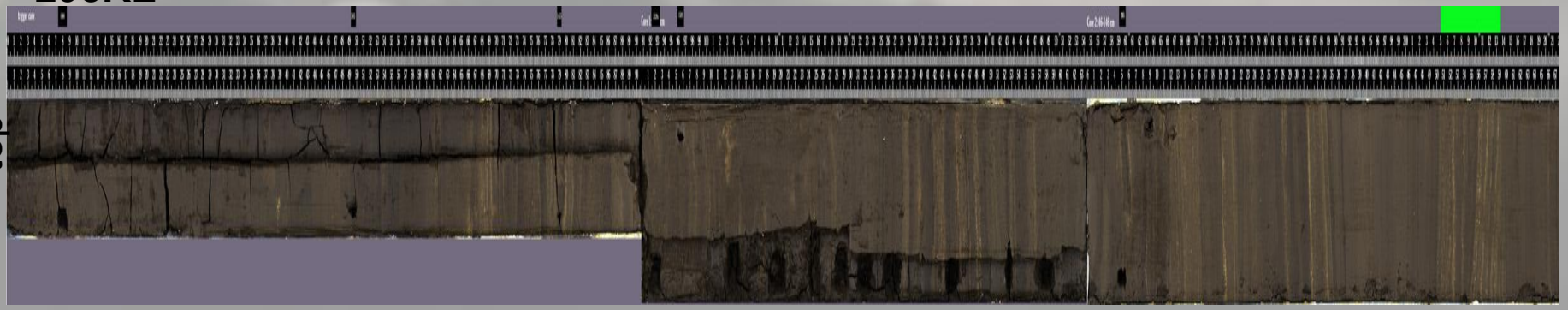
KEY

- Holocene broadly layered sediment
- LGIT laminated sediment
- Pre LGM sediment
- Carbon-14 ages *(in calibrated yr using Marine04 with Δr = 238 ± 49)*

The Cores – Late Holocene

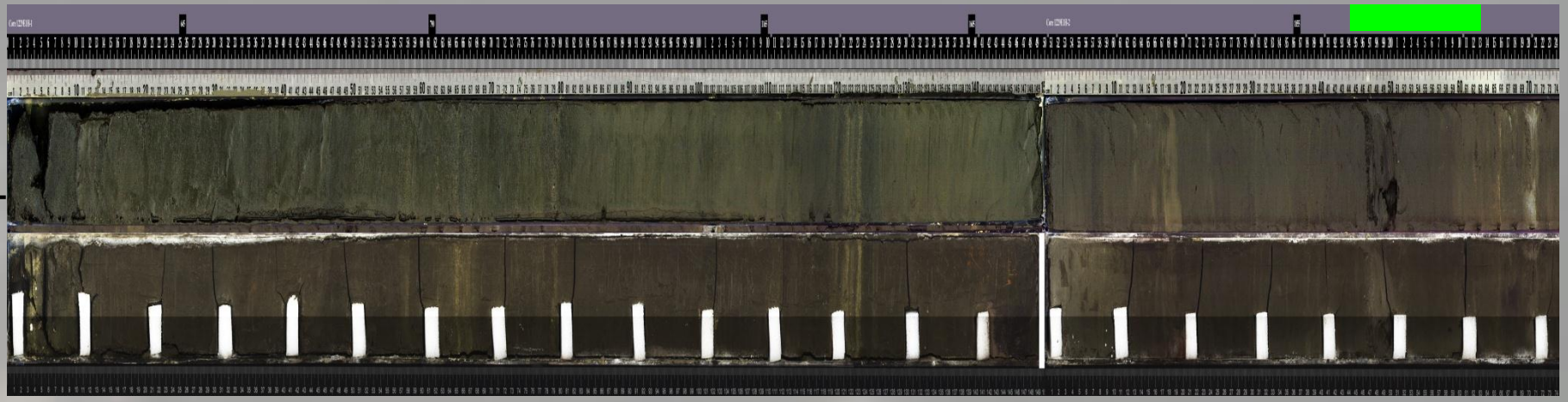
106KL

top



1229E

top



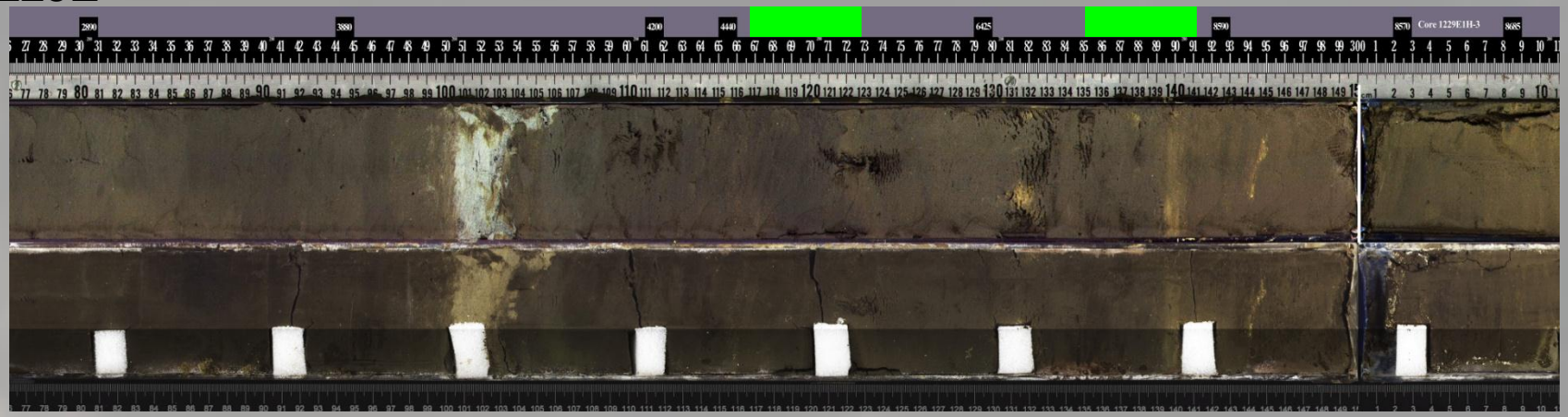
The Cores – Middle Holocene

106KL

top

1229E

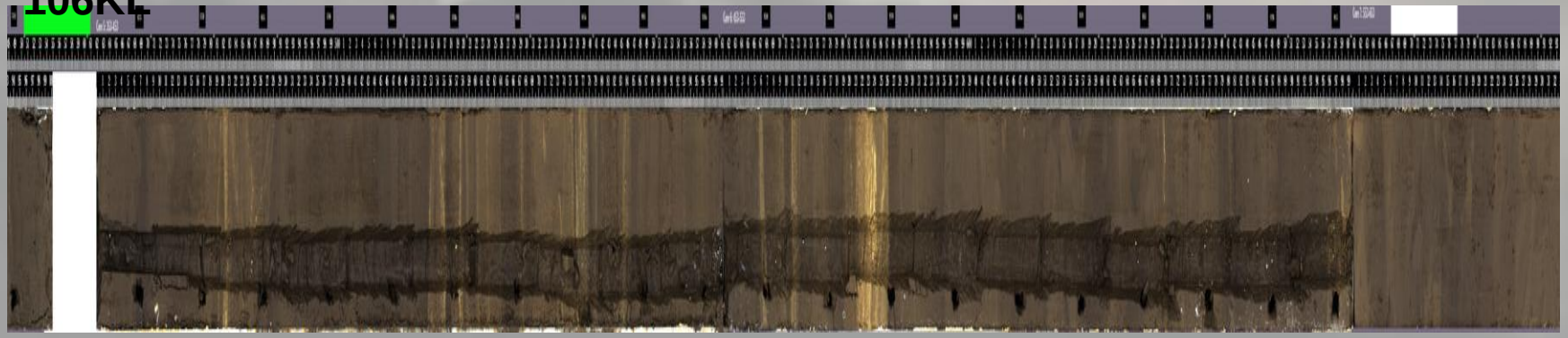
top



The Cores – Early Holocene

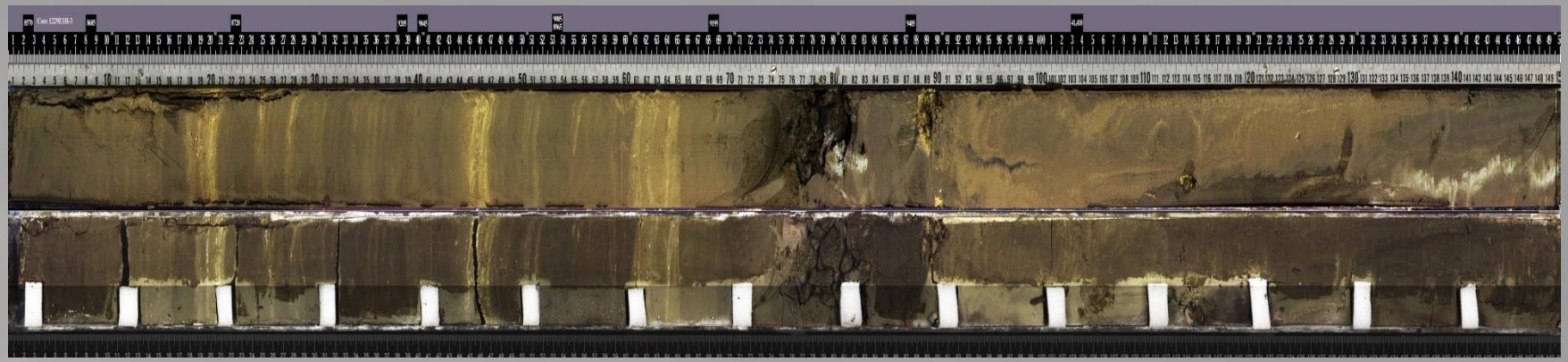
106KL

top



1229E

top



Summary

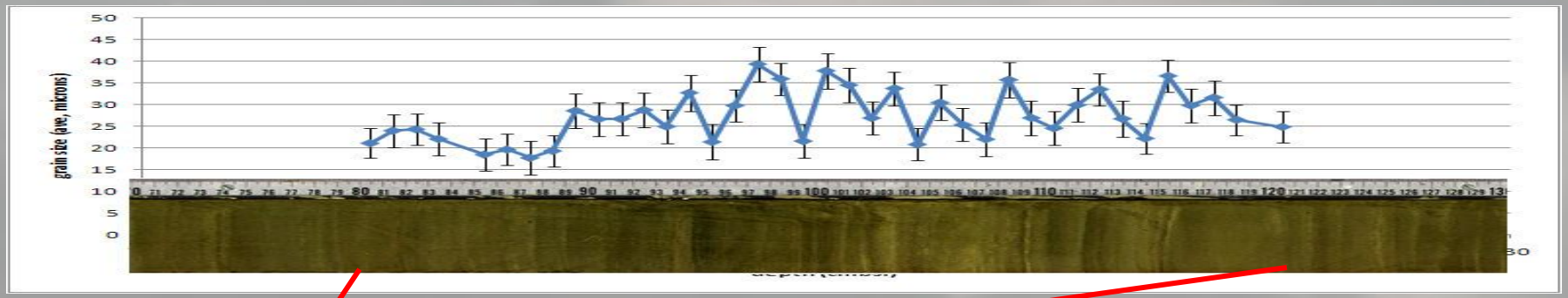
- Sedimentary layers of at least four types
- Middle Holocene time of disruption – evidence of both bioturbation *(slow sedimentation & oxygenated bottom waters?)* and slumping *(increased current velocity)*
- Early and Late Holocene similar in terms of deposition and preservation of laminae
- LGIT – yet to be resolved; geochemically different, extensive slumping, high sedimentation rates, interannual laminations

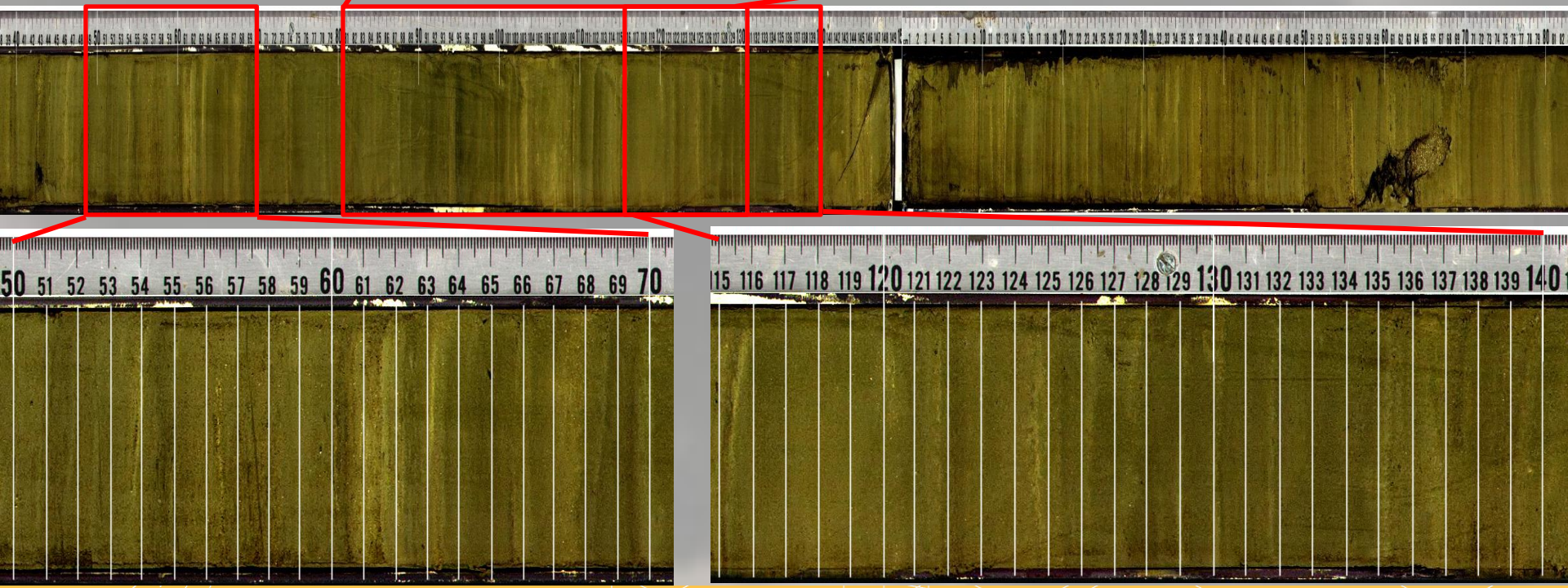
Acknowledgements

- *K41009: Nuclear and isotopic studies of the El Niño phenomenon in the ocean*
- **AINSE (grant numbers 02/169, 04/139, 05/151)**

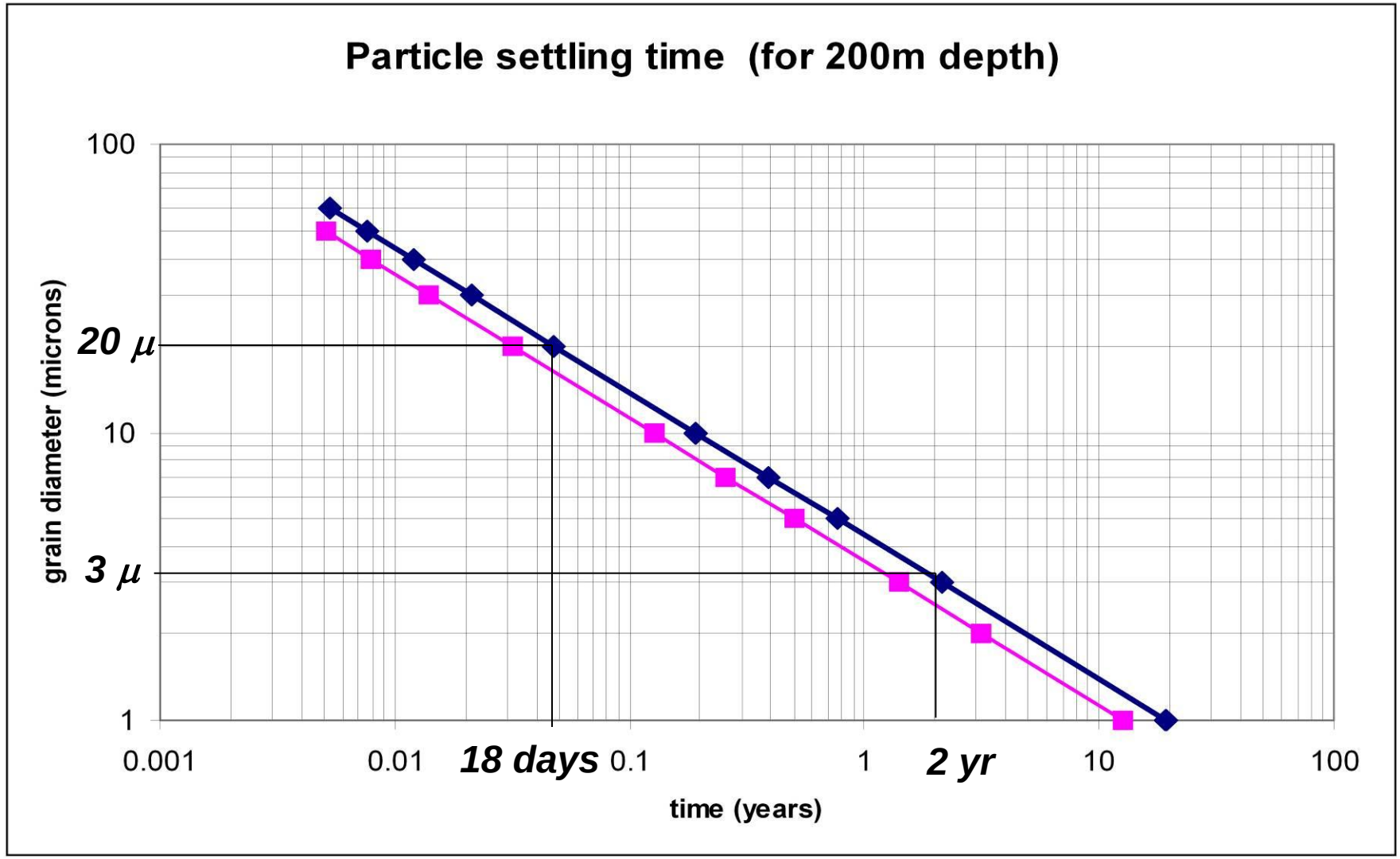
END

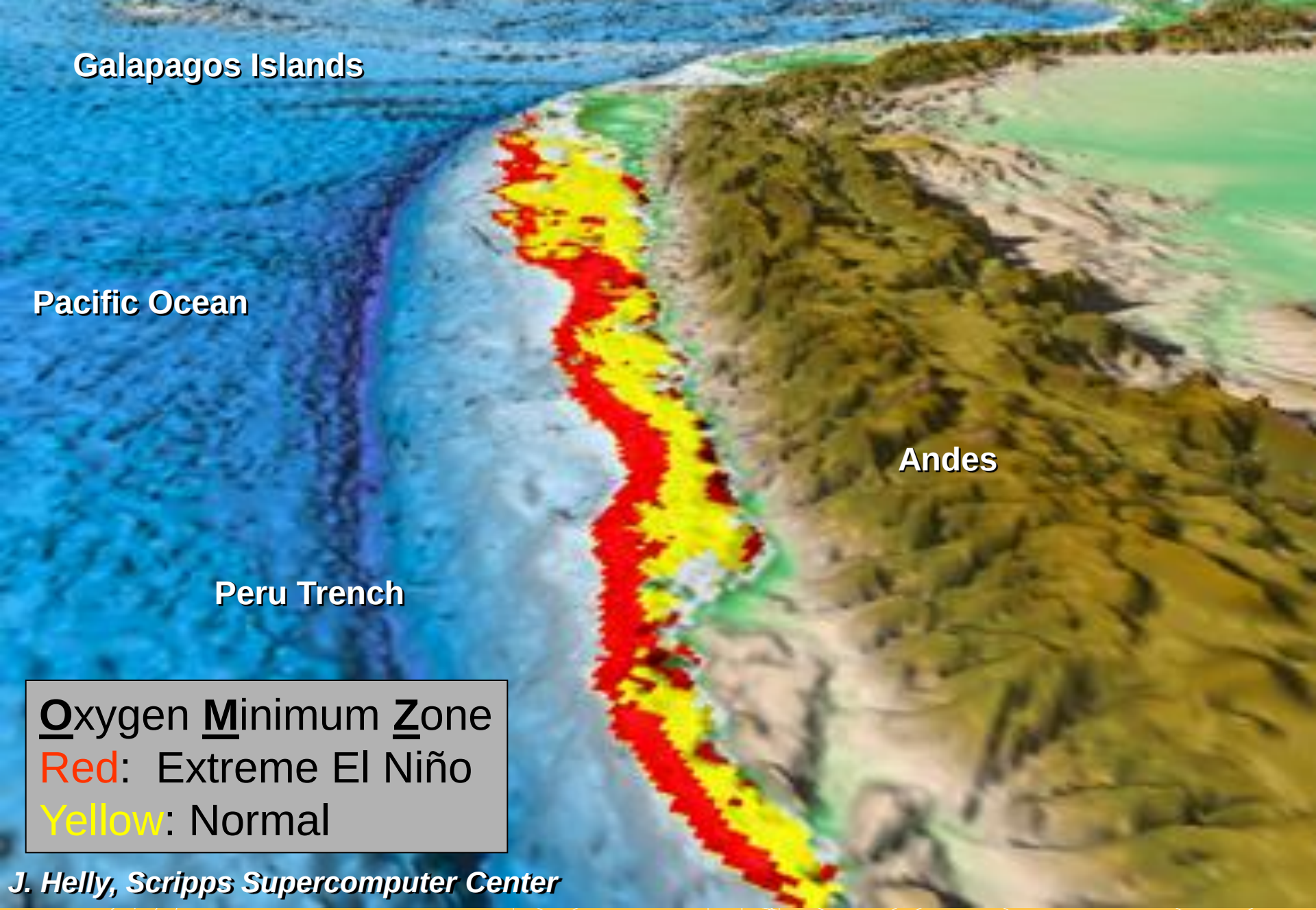
Grain Size



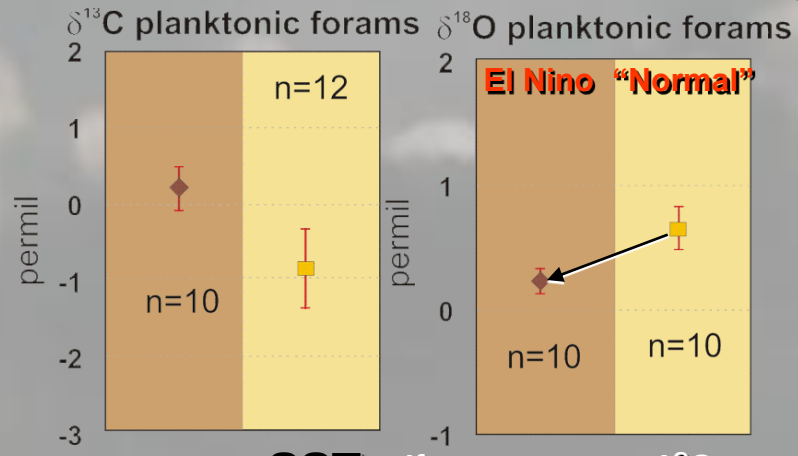


Stokes Settling



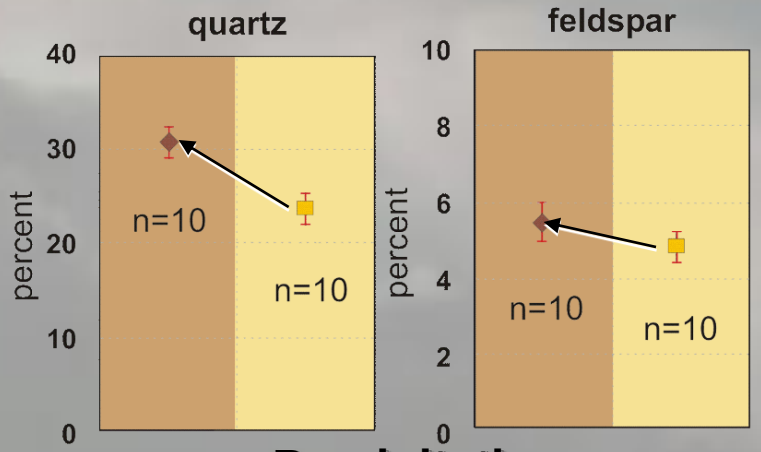

Galapagos Islands
Pacific Ocean
Andes
Peru Trench
Oxygen Minimum Zone
Red: Extreme El Niño
Yellow: Normal
J. Helly, Scripps Supercomputer Center

Geochemical Results

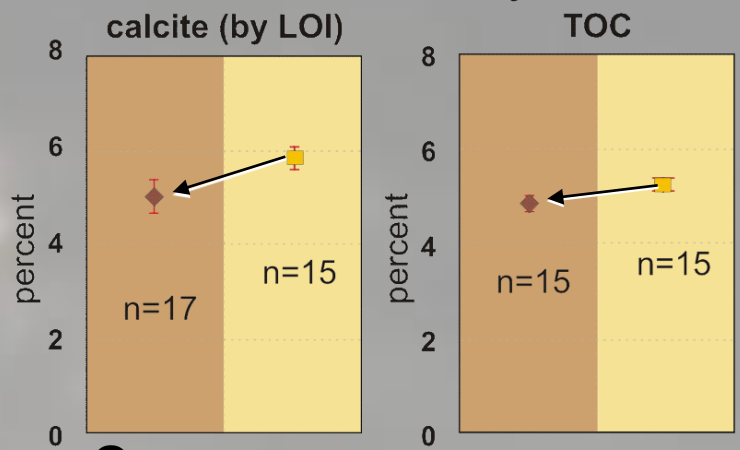


SST

If temperature ~ 1°C warmer
If salinity ~ 0.5 PPT fresher

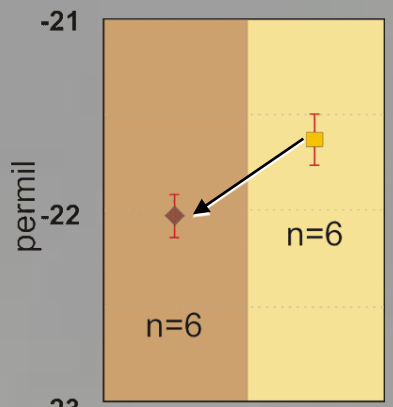


Precipitation



Ocean "productivity"

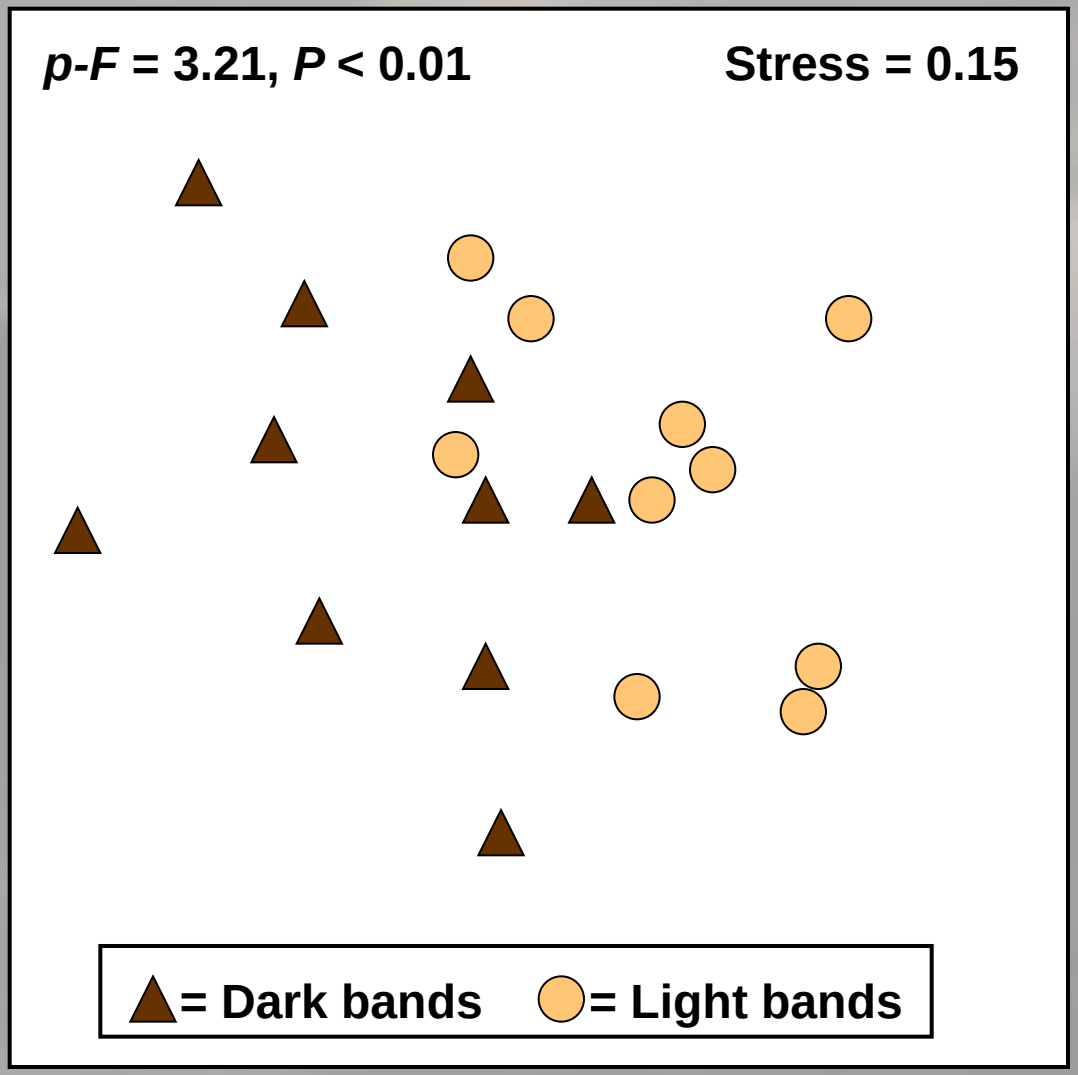
Decreased calcite production
Decreased TOC



Terrestrial vegetation

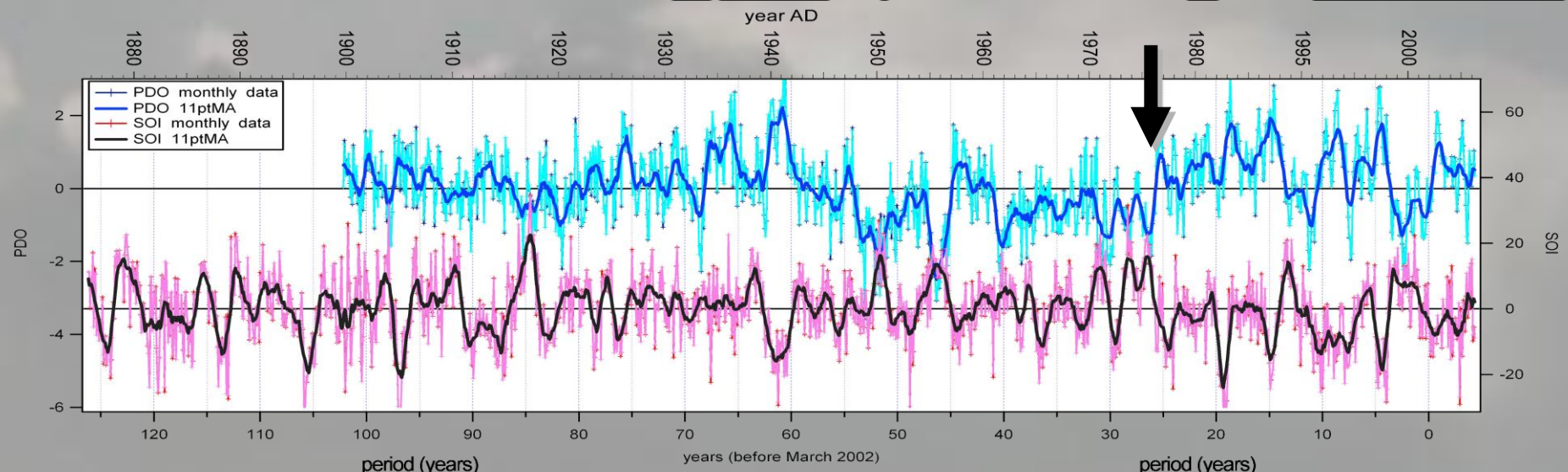
Assume pale = 100% marine with $\delta^{13}C$ -21.5‰ and typical C3 with -27‰, then shift of -0.46‰ ~ 8% terrestrial mixing

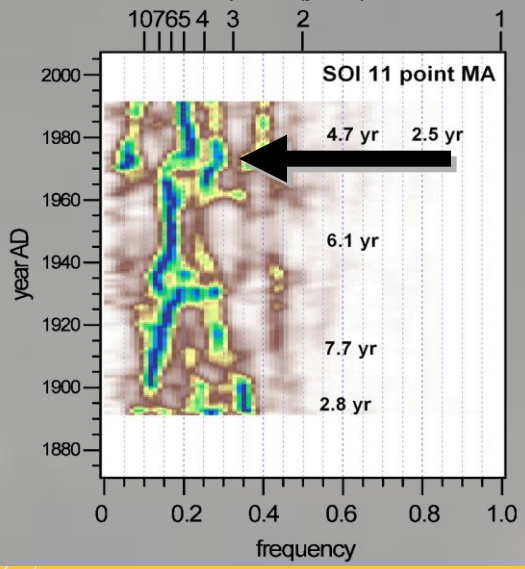
Darker layers are:
- **Warmer**
- **Wetter**
- **Reduced "productivity"**



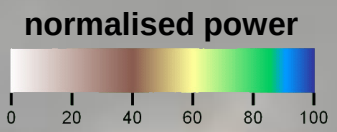
Results of non-parametric multivariate comparison of dark vs light bands. Data are Normalised and Euclidean distance coefficient was used. nMDS is used to graphically represent the comparison and NP-MANOVA was used to test the hypothesis.

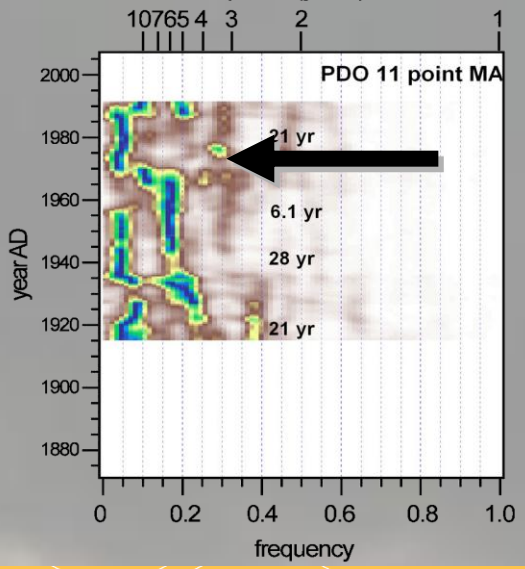
Modern ENSO Time Series





Trenberth & Hurrell (1993)
Zhang *et al.* (1997)
Urban *et al.* (2000)



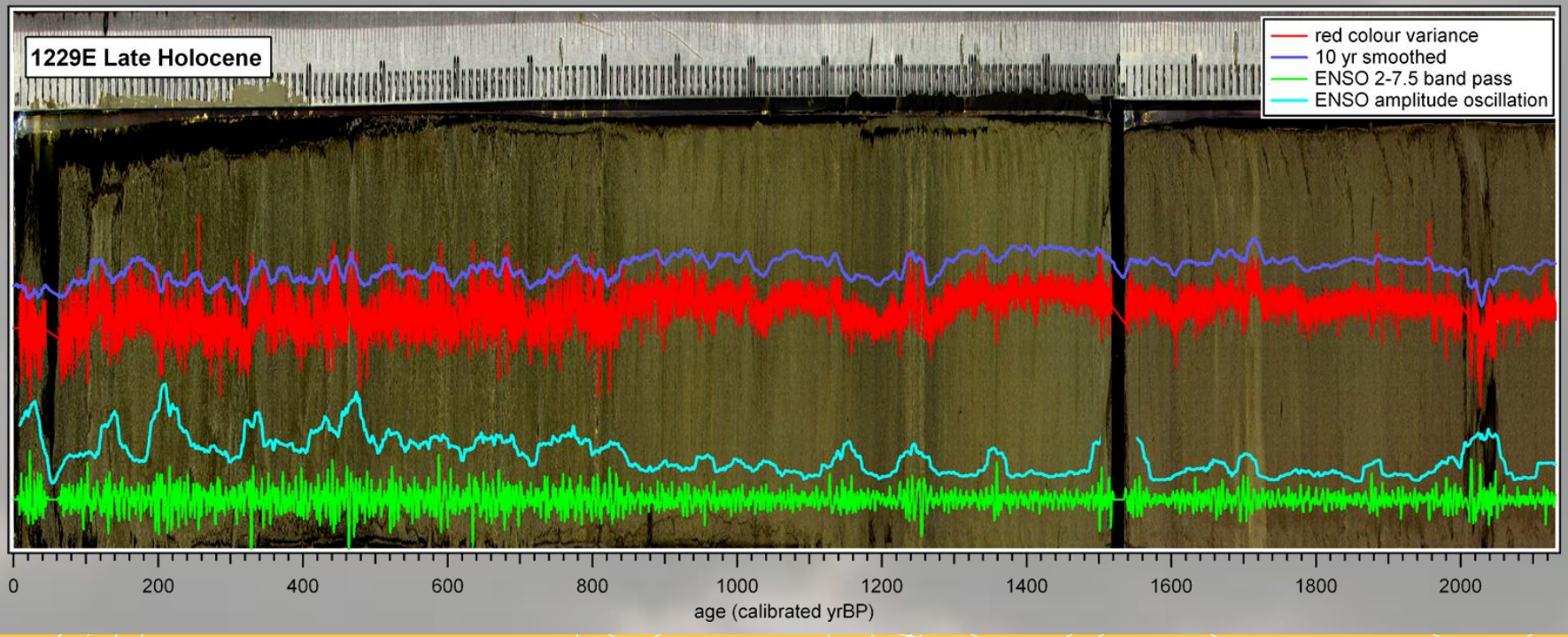


Time Series

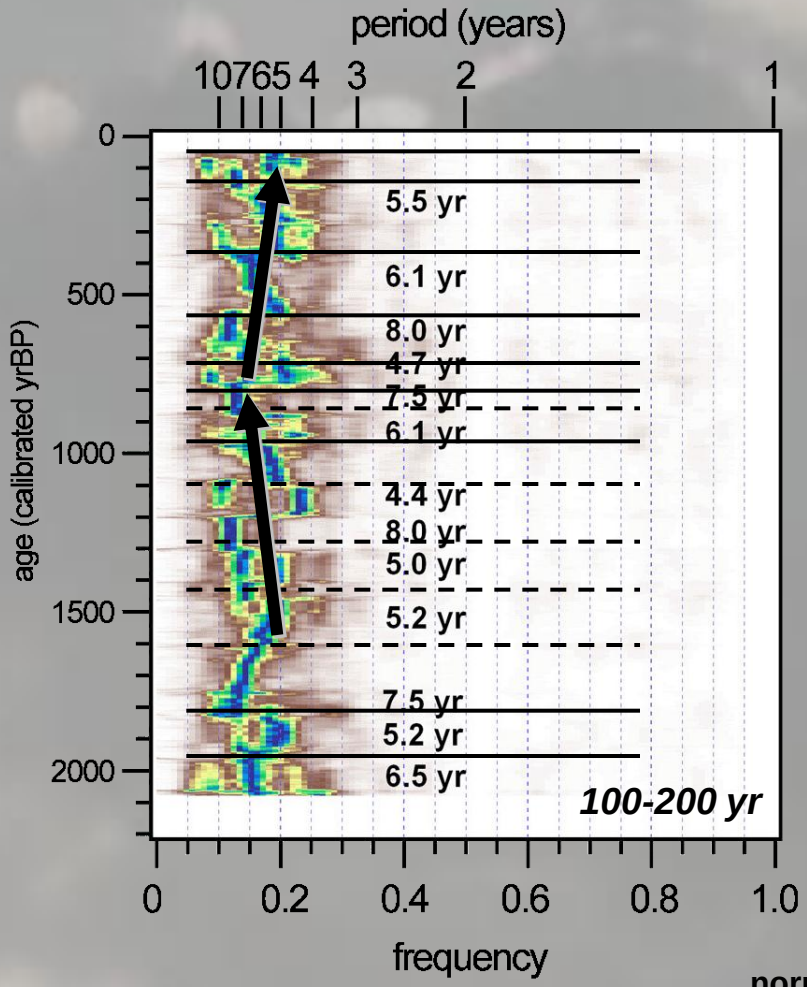
Three Sets of Spectral Analyses:

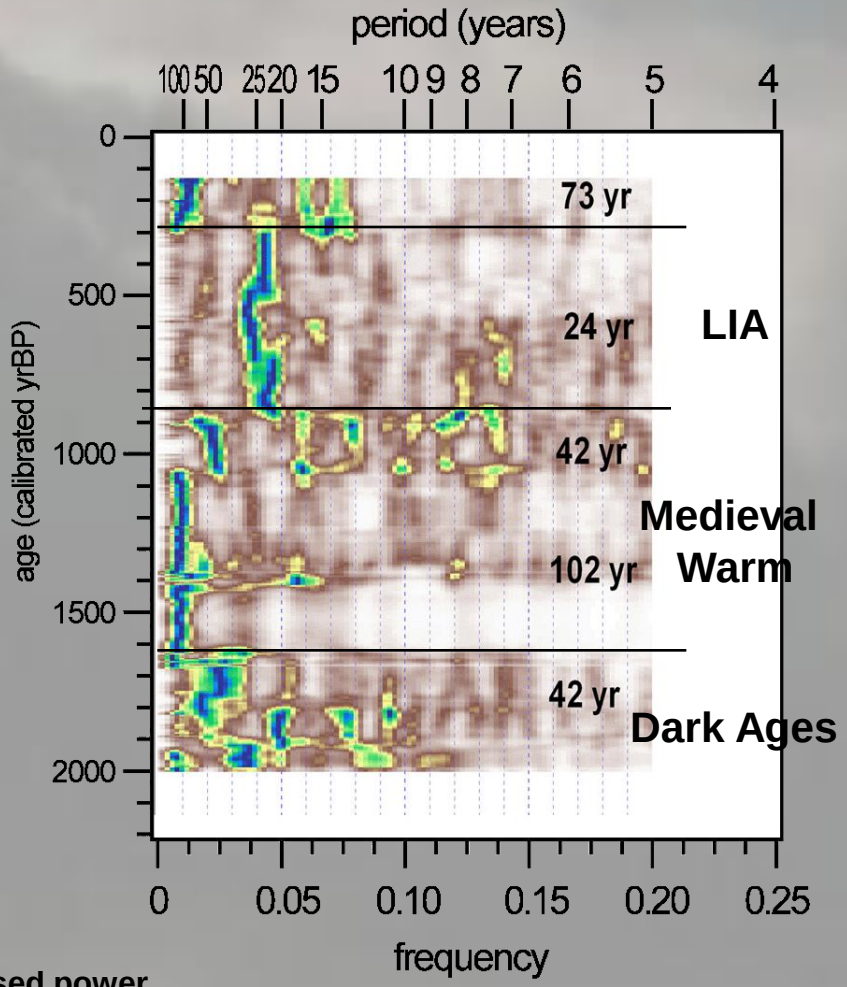
(Evolving spectrograms of normally-distributed data using Blackman-Tukey FFT with Hanning window)

- Red colour intensity of interannual ENSO (band pass filter to extract 2-7.5 yr variance – **green curve**)
- Amplitude modulation of interannual ENSO – **aqua curve**
- Layer trends (events per 100 yr)



Late Holocene Time Series 1229E



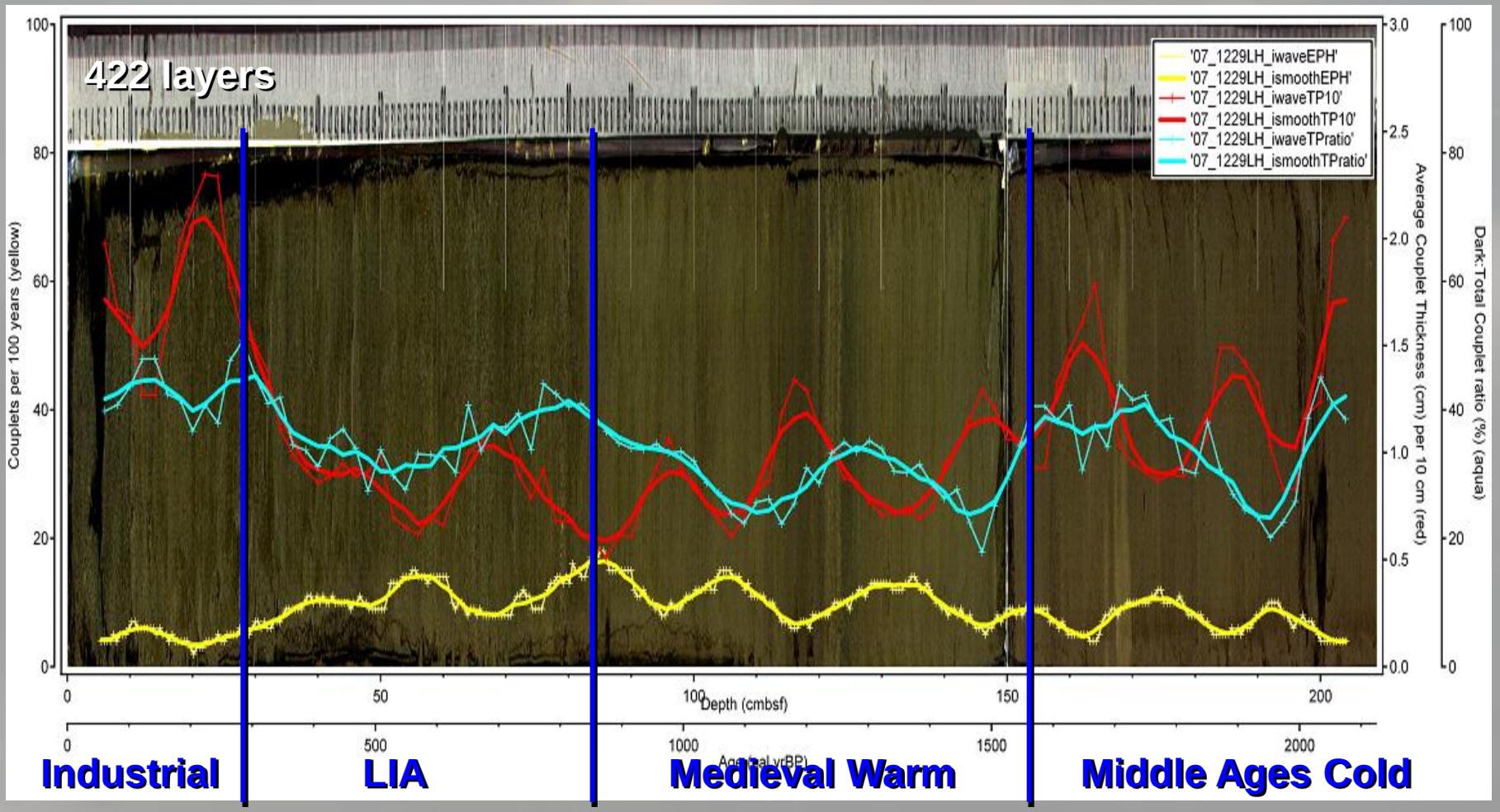


normalised power

0 20 40 60 80 100

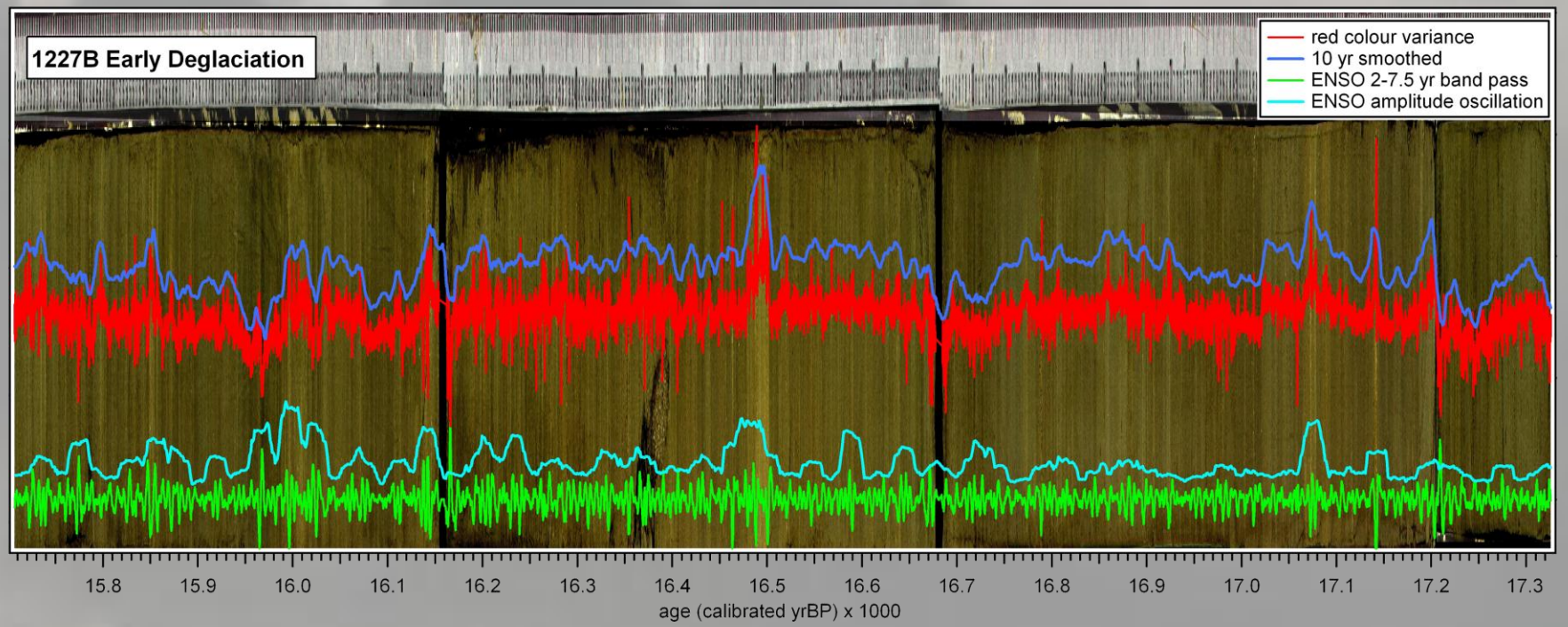
ENSO band variance

amplitude modulation

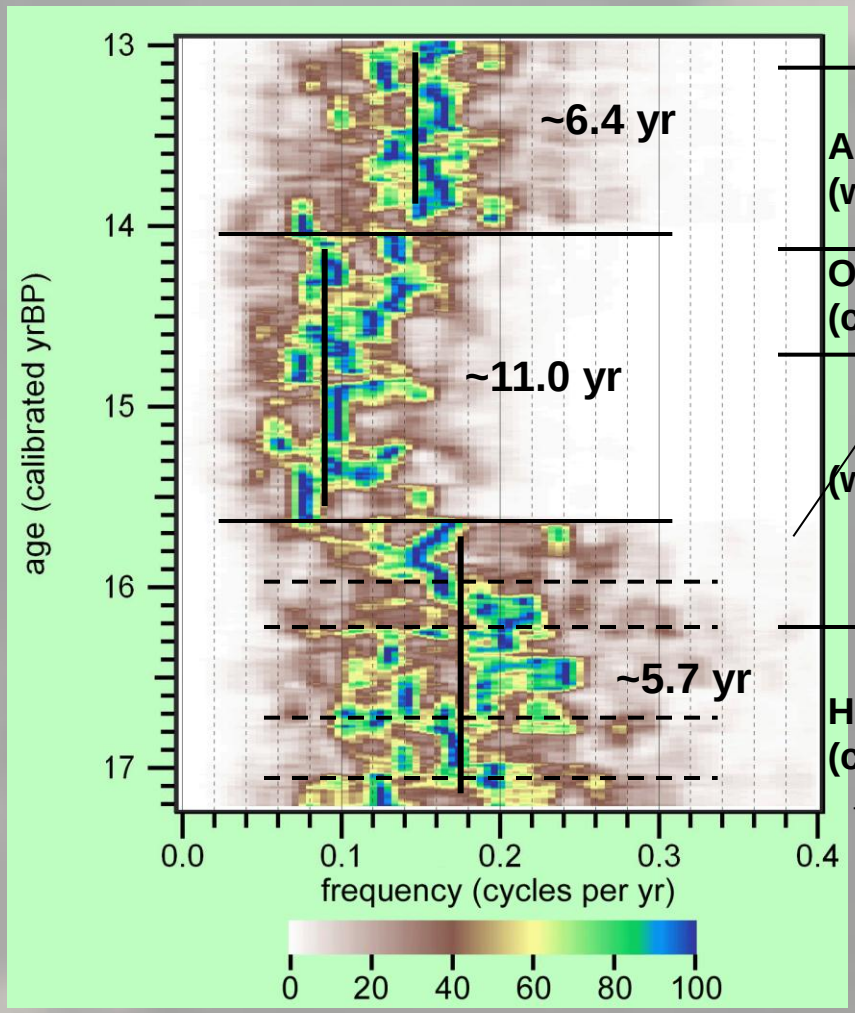


- Frequency ~ 220 yr (Suess?)
- Inverse correlation between events per 100 years and thickness per 10 cms (*i.e. if more layers per time, they are thinner ~constant sedimentation rate*)
- ~ inverse correlation between thickness per 10 cm and % dark per couplet (*i.e. where there are more events per 100 yr, ENSO (dark) part of the couplet is dominant)*
- Recent past compaction articfact?

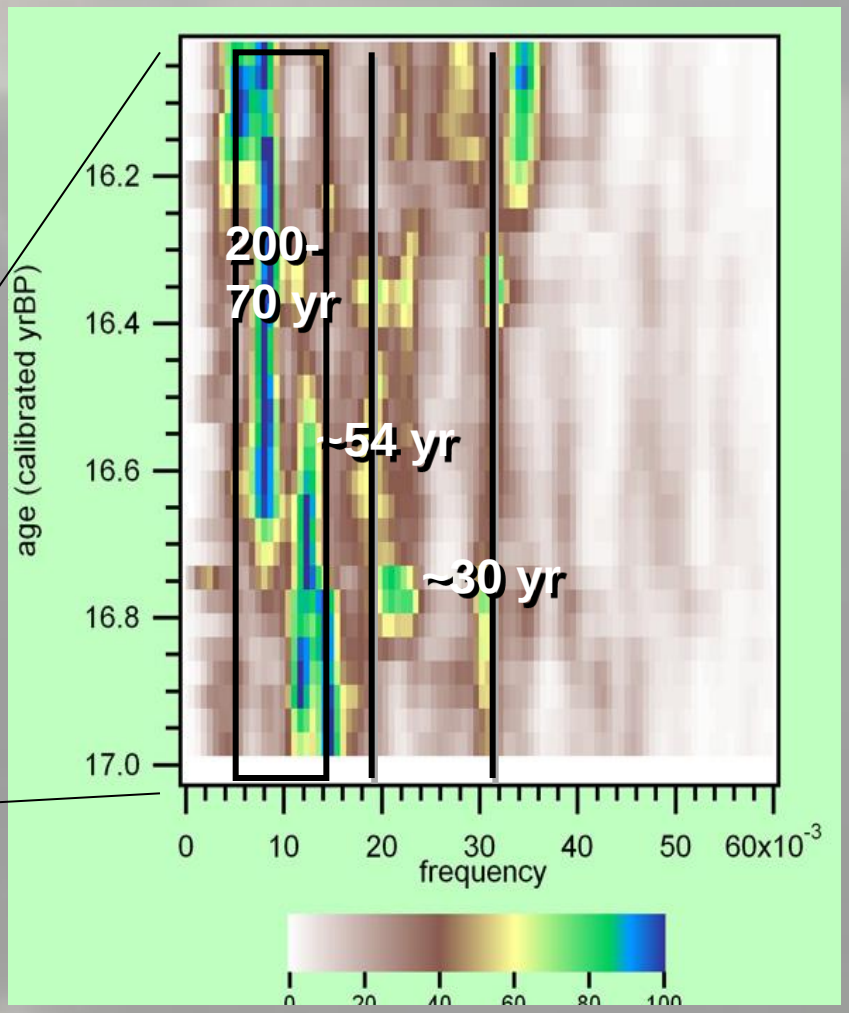
Early Deglaciation Time Series 1227B



Deglaciation Time Series 1227B



Evolving spectrum ENSO variance



Evolving spectrum amplitude oscillation