Milankovitch-Controlled Paleoclimate Signal Recorded by Rock Magnetics, Lower Cretaceous Platform Carbonates of Northern Mexico*

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Search and Discovery Article #40388 (2009)
Posted February 5, 2009

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

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Abstract

Study of cyclic carbonate platforms relies on field observations of repeating, often cryptic, shallowing upward facies. This can be difficult when cycles are thin or lack lithologic distinction. The cyclicity typically occurs at Milankovitch time scales, and needs to be analyzed for orbital forcing. An assessment of how the signal is encoded in the rocks is integral to assessing the validity of climate proxies. The challenge is how to render measured sections into objective time series using a facies-independent physical parameter.

Here we report on anhysteretic remanent magnetism (ARM) of the lower Aptian Cupido Formation, which reveals 150 m of pervasive, non-random variations at sites from the inner and middle shelf (30 km apart). Fine-grained detrital magnetite from terrigenous sediment, possibly eolian dust, is responsible for the ARM. At both sites, ARM variations show a synchronous ~30-35 m oscillation with maxima coinciding with fourth-order sequence boundaries, superimposed by prominent high-frequency variability. Chronostratigraphy suggests that the variations reflect Milankovitch cycles. Tuning the low-frequency oscillation to a 405-kyr periodicity (long eccentricity) focuses high-frequency variability into short eccentricity, obliquity and precession bands; the precession-band signal modulates with a pronounced eccentricity signature.

The ARM signal is tightly correlated between the sites, but decoupled from interpreted fifth-order depositional cycles. ARM amplitude weakens upsection as facies record deepening conditions, likely due to a warming, humid climate, changing global circulation and/or greater dispersal of magnetite grains in the water column. The high fidelity of this ARM proxy underscores its great promise in the objective retrieval of Milankovitch cycles, and in the high-resolution stratigraphic correlation of carbonate platforms.

Milankovitch-controlled paleoclimate signal recorded by rock magnetics, Lower Cretaceous platform carbonates of northern Mexico

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OUTLINE

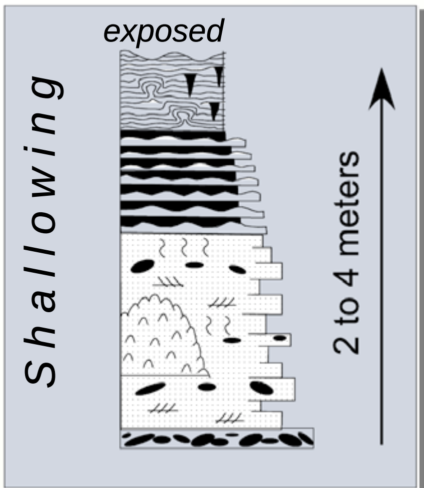
- Analyzing cyclic carbonate platforms
  - -time-honored approach: facies analysis
  - -emerging approach: rock magnetics
- Cretaceous Cupido Platform, Mexico
  - -geologic setting; stratigraphic framework
  - -Potrero Garcia and Potrero Chico
  - -cycle thickness stacking pattern
- Rock magnetism analysis
  - -anhysteretic remanent magnetism (ARM)
  - -ARM correlation between Garcia and Chico
  - -ARM signal decoupled from depositional cycles
- Milankovitch-controlled paleoclimate signal
  - -ARM signature of long-term climate change
  - -record of eccentricity, obliquity and precession index
- Conclusions

• Analyzing cyclic carbonate platforms

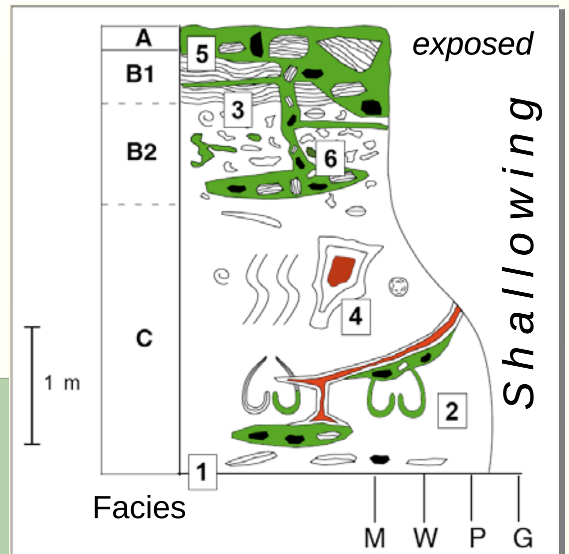
-time-honored approach: facies analysis

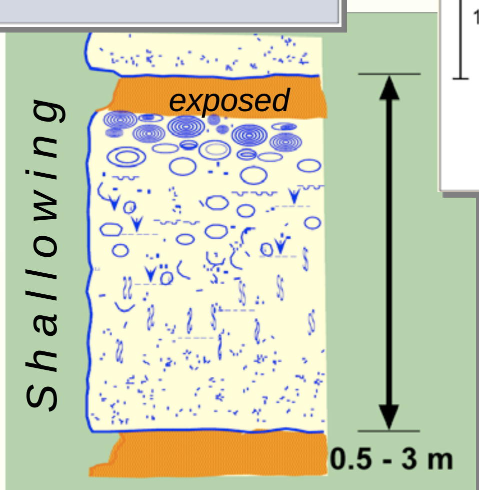
EXAMPLES OF METER-SCALE CYCLES

Aisha-Bibi cycles
Cambrian, Kazakhstan
Bazykin & Hinnov, 2002



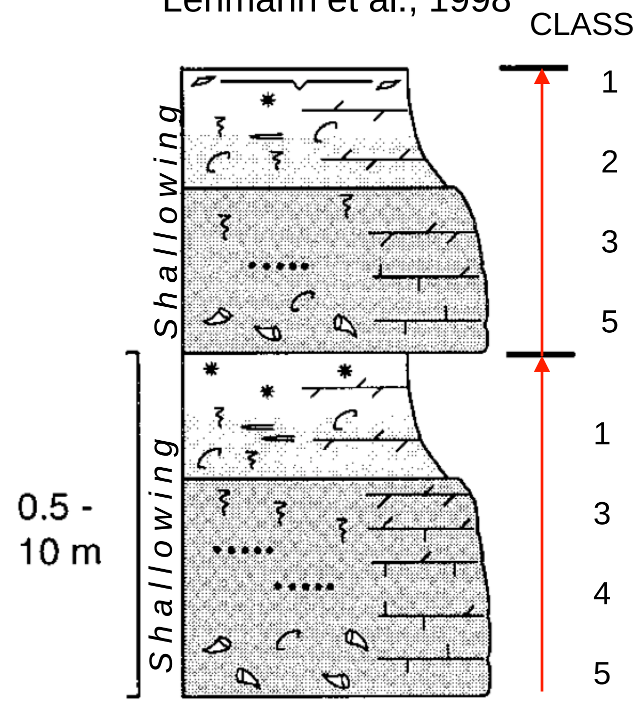
Dachstein cycles
Triassic, Italy
Cozzi et al., 2005





Latemar cycles
Triassic, Italy
Goldhammer et al., 1987

Cupido cycles
Cretaceous, Mexico
Lehmann et al., 1998



LITHOLOGIC CLASS
1 = Subaqueous Gypsum
2 = Laminites
3 = Heterolithic Thin Beds
4 = Burrowed Wackestones
5 = Non-skeletal Packstone

• Analyzing cyclic carbonate platforms

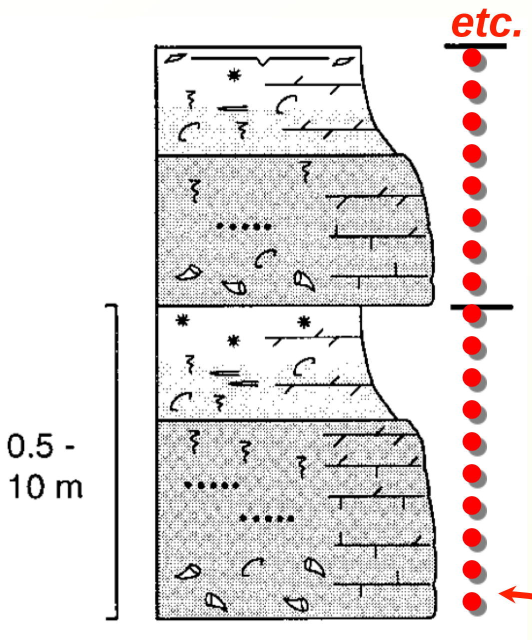
-emerging approach: rock magnetics

ARM

Anhysteretic Remanent Magnetization

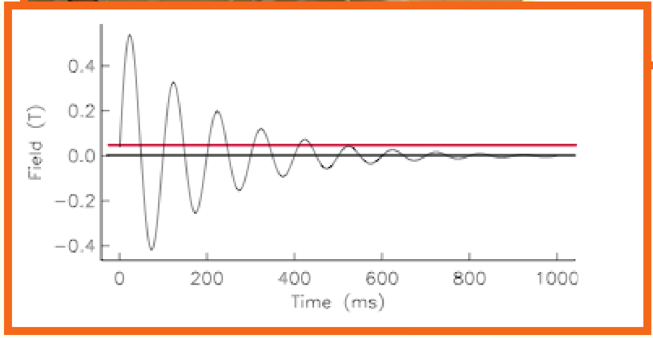
<5μm ferrimagnetic minerals

Coercivities <100mT



High-resolution sampling for <u>better definition of cycles</u> and complete recovery of <u>signal within cycles</u>

…lots of samples!

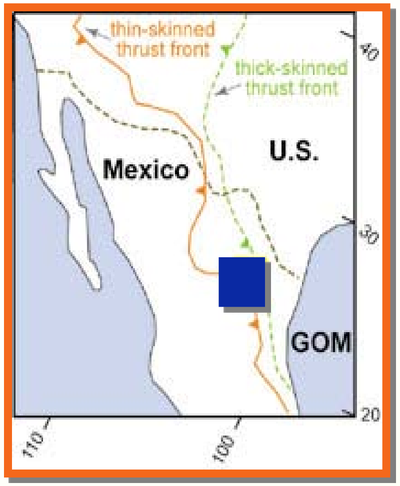


Fast
Cheap
Nondestructive!

• Cretaceous Cupido Platform, Mexico

-geologic setting; stratigraphic framework

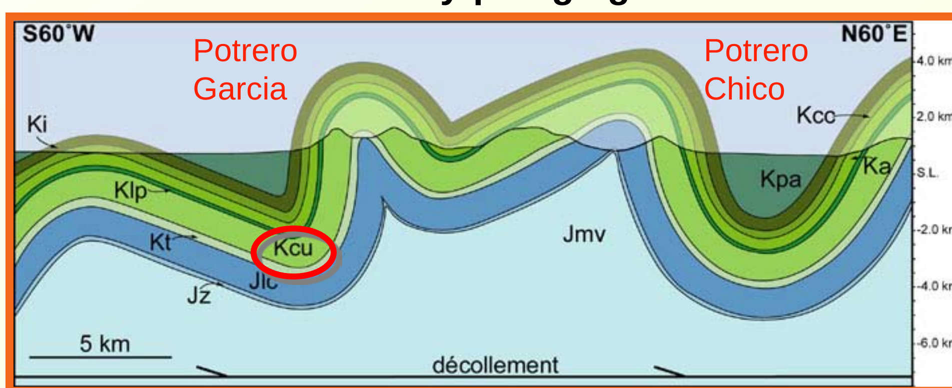
Coahuila Marginal Fold-Thrust Province, NE Mexico



Age		Formation	Thickness
Cretaceous	Upper	Parras Shale	1220 m
Cretaceous	Upper	Indidura	530 m
Cretaceous	Lower	Cuesta del Cura	85 m
Cretaceous	Lower	Aurora	250 m
Cretaceous	Lower	La Peña	25 m
Cretaceous	Lower	Cupido	940 m
Cretaceous	Lower	Taraises	490 m
Jurassic	Upper	La Casita	1070 m
Jurassic	Upper	Zuloaga	60 m
Jurassic	Upper	Minas Viejas	3020+ m

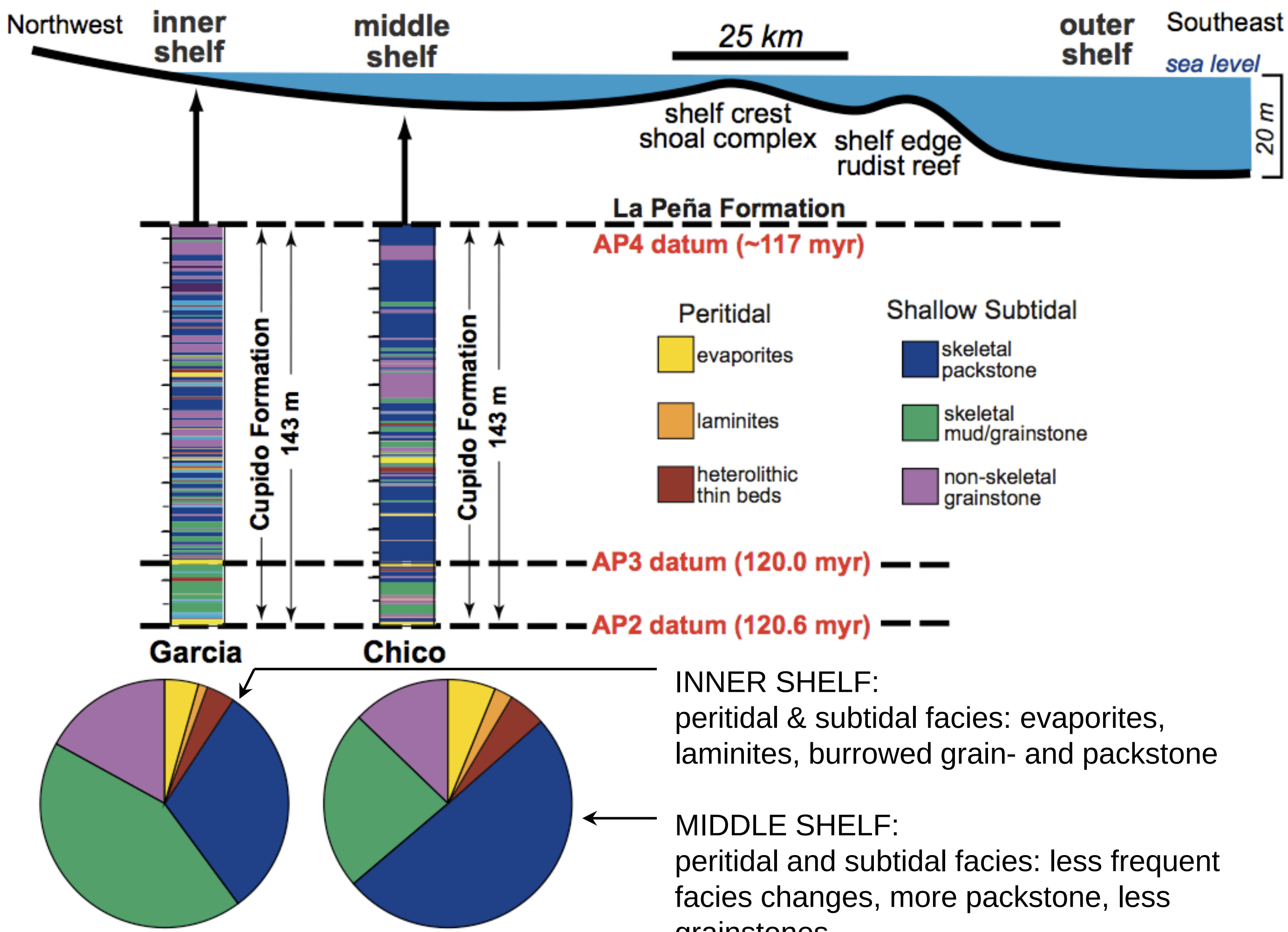
L. Aptian

Sierra del Fraile doubly-plunging anticlinorium



• Cretaceous Cupido Platform, Mexico

-Garcia and Chico sections

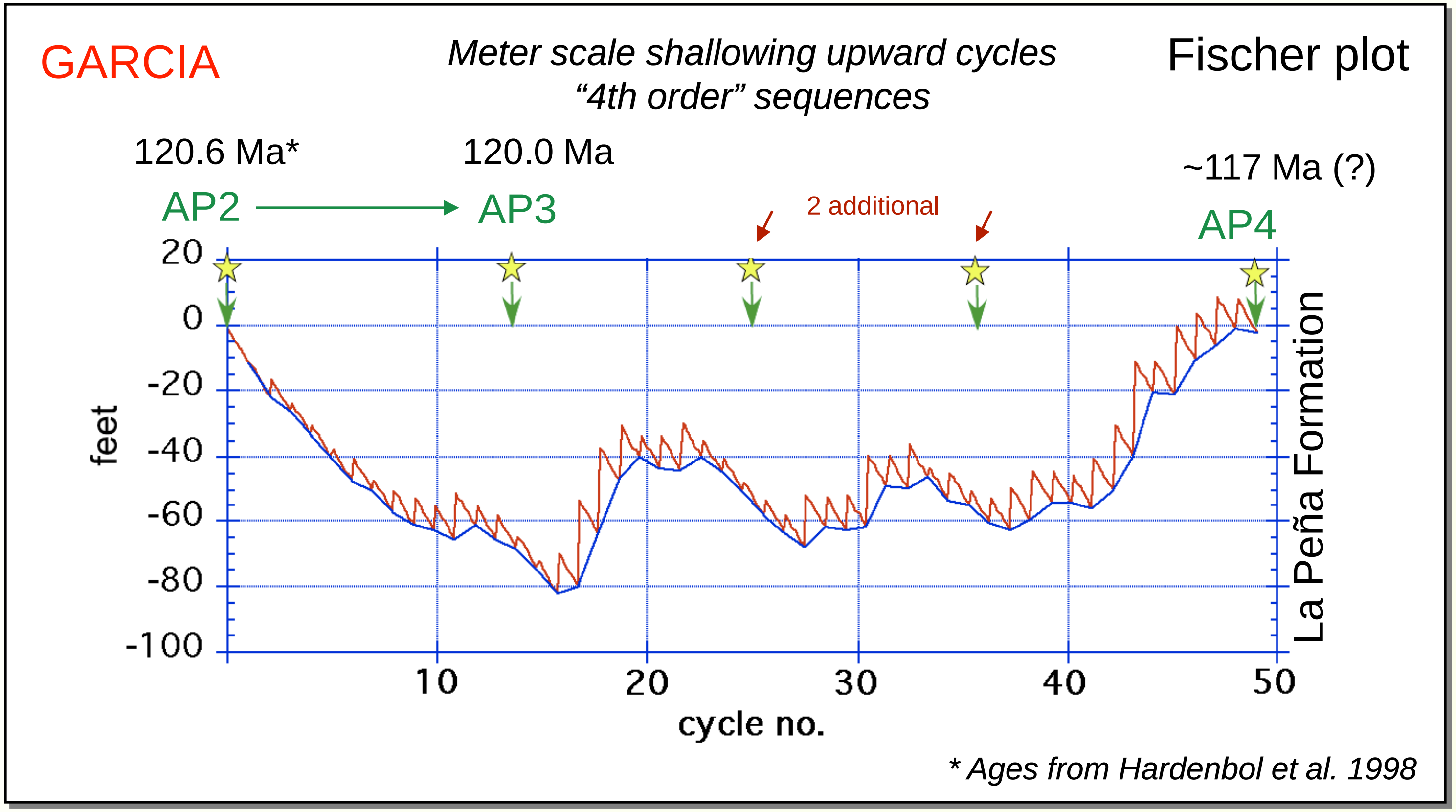


INNER SHELF:
peritidal & subtidal facies: evaporites, laminites, burrowed grain- and packstone

MIDDLE SHELF:
peritidal and subtidal facies: less frequent facies changes, more packstone, less grainstones

• Cretaceous Cupido Platform, Mexico

-cycle thickness stacking patterns



Results:

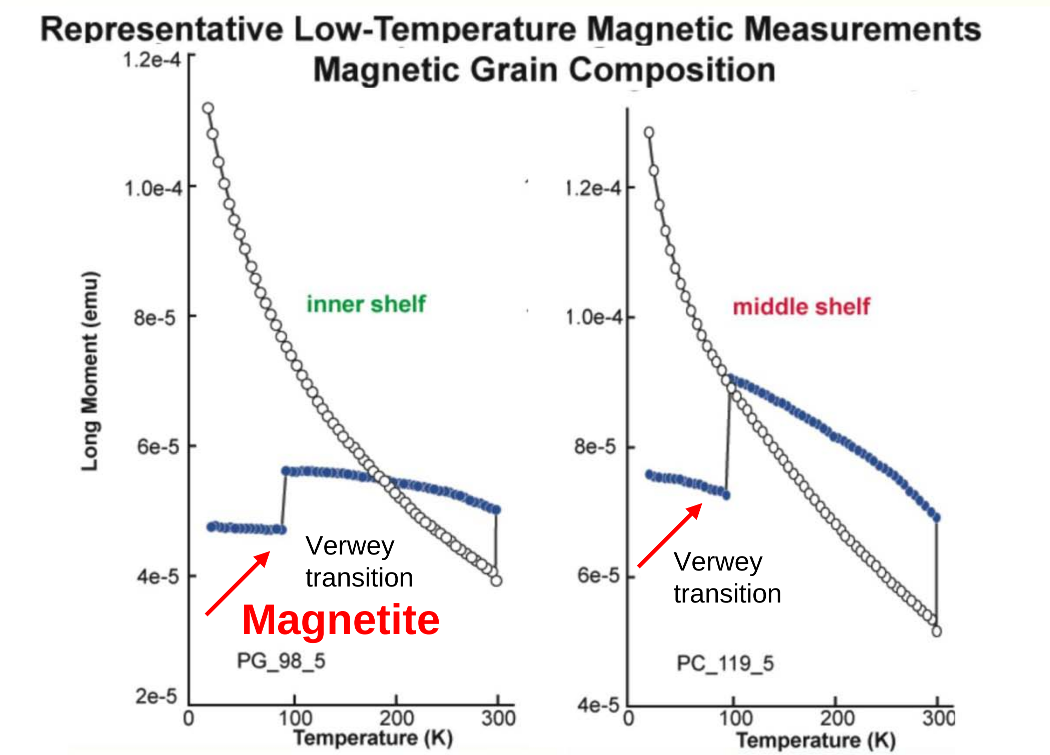
- section duration: ~3.6 myrs
- cycle durations: ~73 kyrs
- sequence durations: ~730-900 kyrs
- ~10-12 cycles per sequence
- no sustained 5:1 cycle bundling!

• Rock magnetism analysis

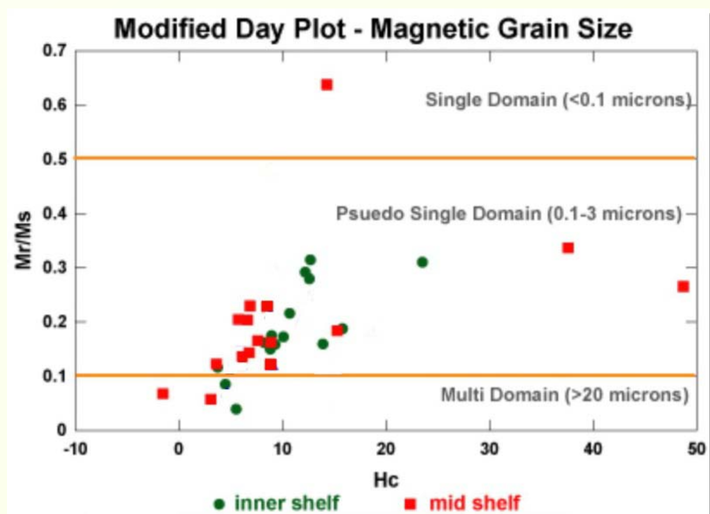
-anhysteretic remanent magnetism (ARM)

ARM is a measure of the concentration of ferrimagnetic minerals, is insensitive to changes in carbonate content, thus is an ideal tool for evaluating sediment cycling independent of facies.

Source of ARM signal in Cupido cycles is fine-grained magnetite.



Measurements made on the Magnetic Properties Measurement System (MPMS), Univ. of Minnesota.

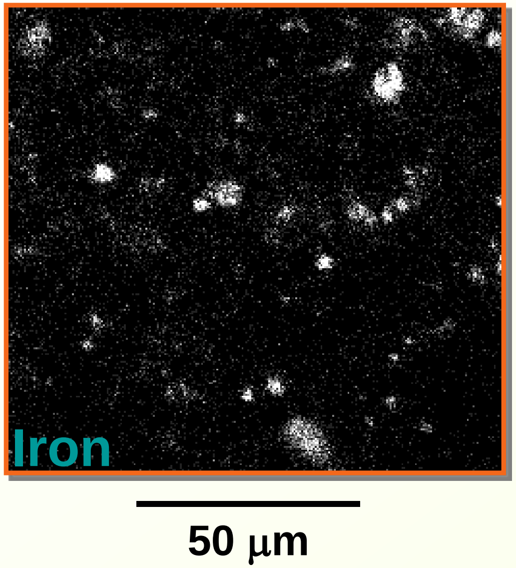


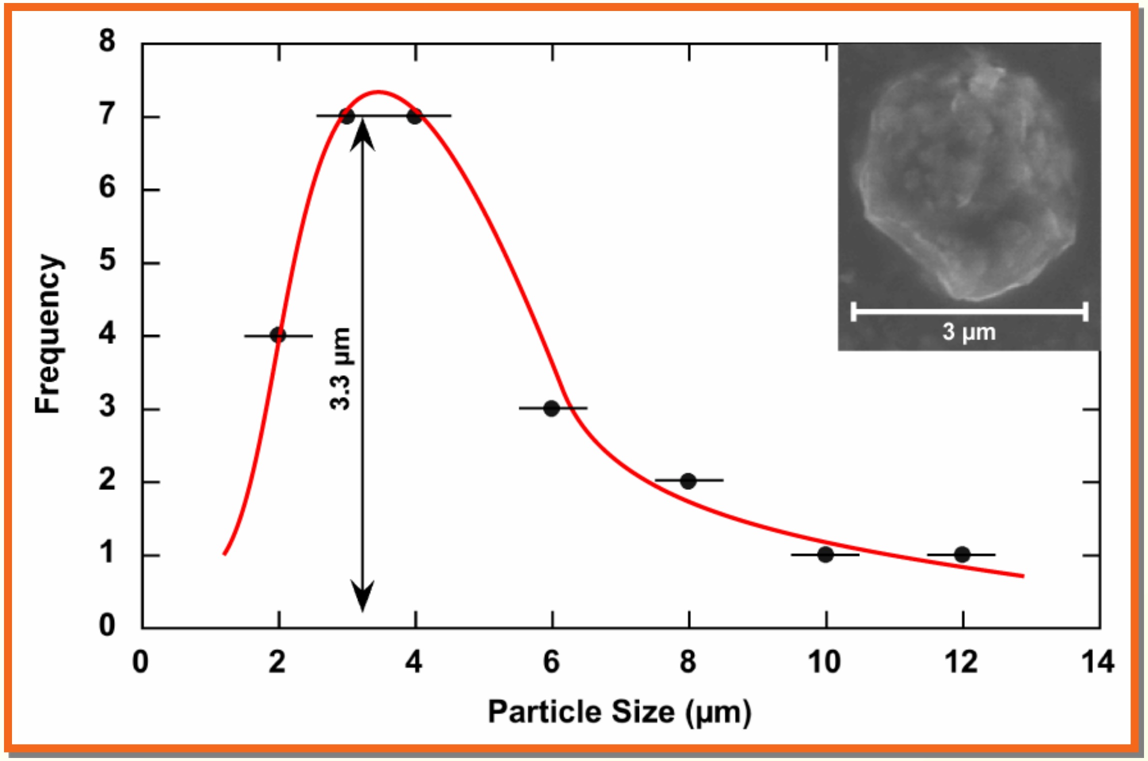
• Rock magnetism analysis

-ARM source: fine-grained detrital magnetite

SEM AND XRD ANALYSES

- Primary magnetite
- Quartz coatings
- Fine-grained
- Rare sulfides
- No magnetosomes

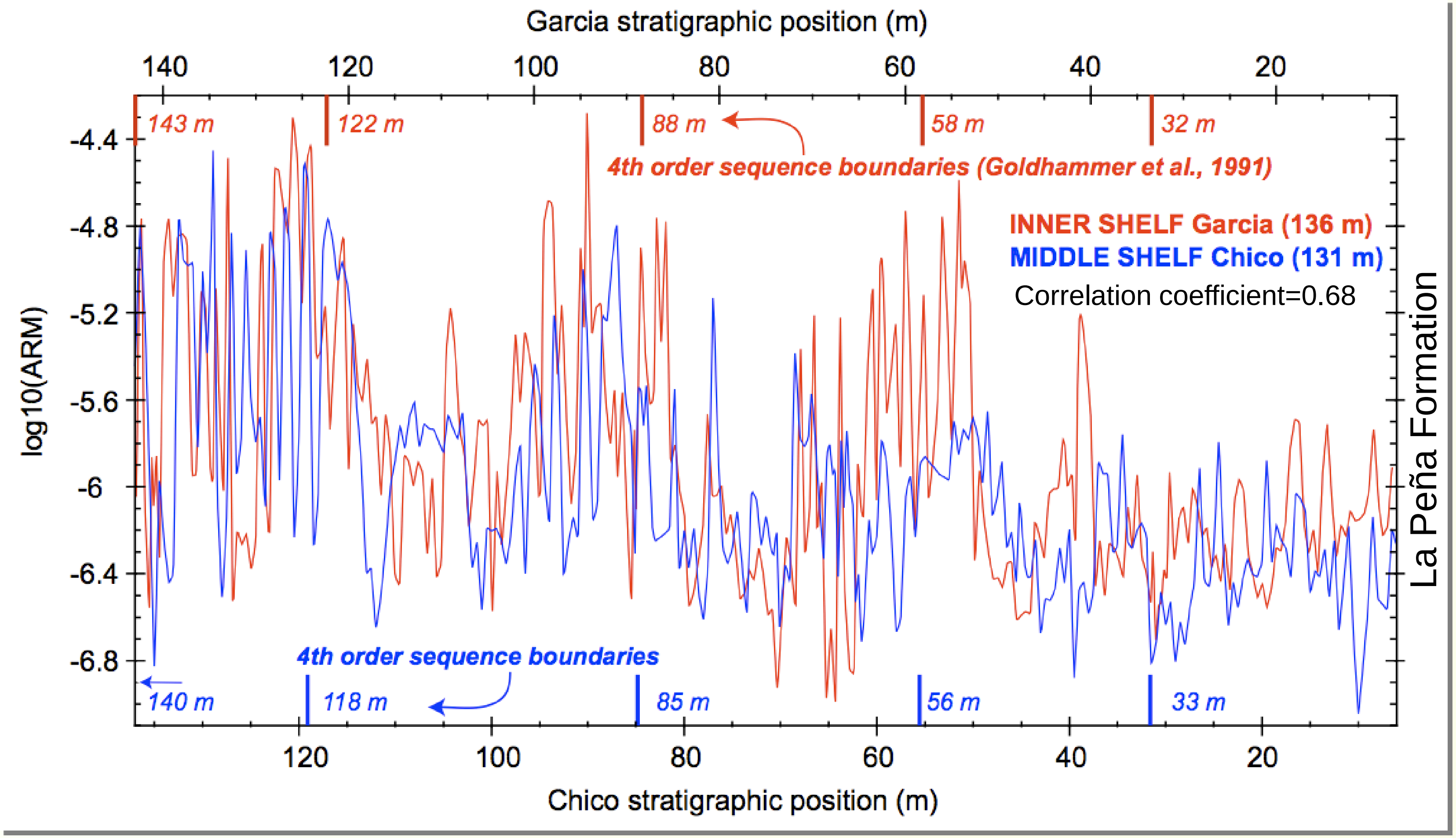




Magnetite grain sizes and shapes are consistent with far-traveled atmospheric dust particles

• Rock magnetism analysis

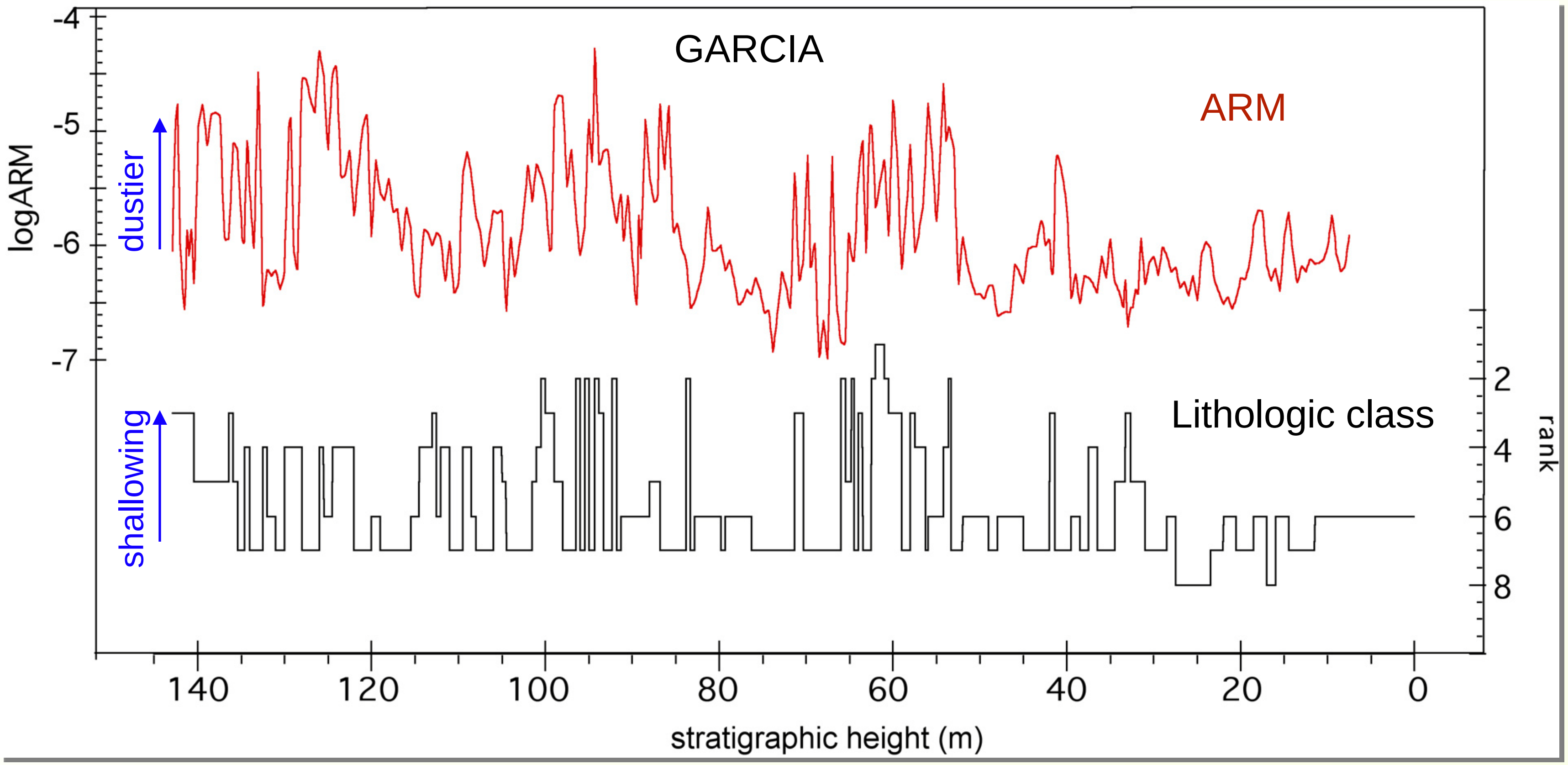
-ARM correlation between Garcia and Chico



- Both sections overlain conformably by deep water La Peña Formation
- Garcia has consistently higher ARM values than Chico (higher dust concentration)
- Both series have same long-period variation; maxima phased with sequence boundaries

• Rock magnetism analysis

-ARM decoupled from depositional facies



Lithologic class (ranked by relative depth)

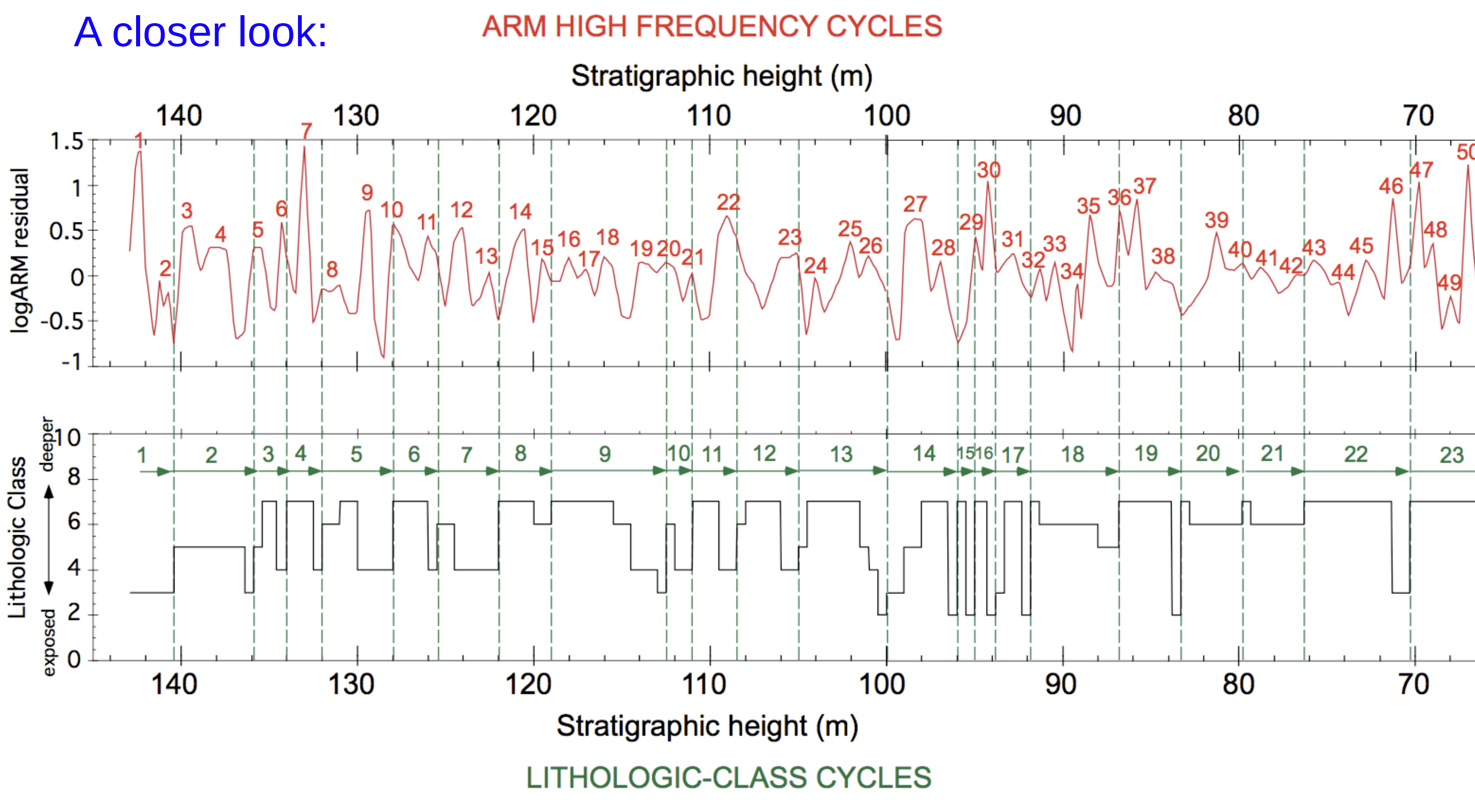
1 = Subaqueous Gypsum
2 = Laminites
3 = Heterolithic Thin Beds
4 = Thalassanoides Burrowed Wackestones
5 = Non-Skeletal Grainstones
6 = Bedded Requienids & Chrondrodonts
7 = Skeletal Packstones
8 = Rudistid Bioherms

Adapted from Foster (2003)

• Rock magnetism analysis

-ARM decoupled from depositional facies

A closer look:



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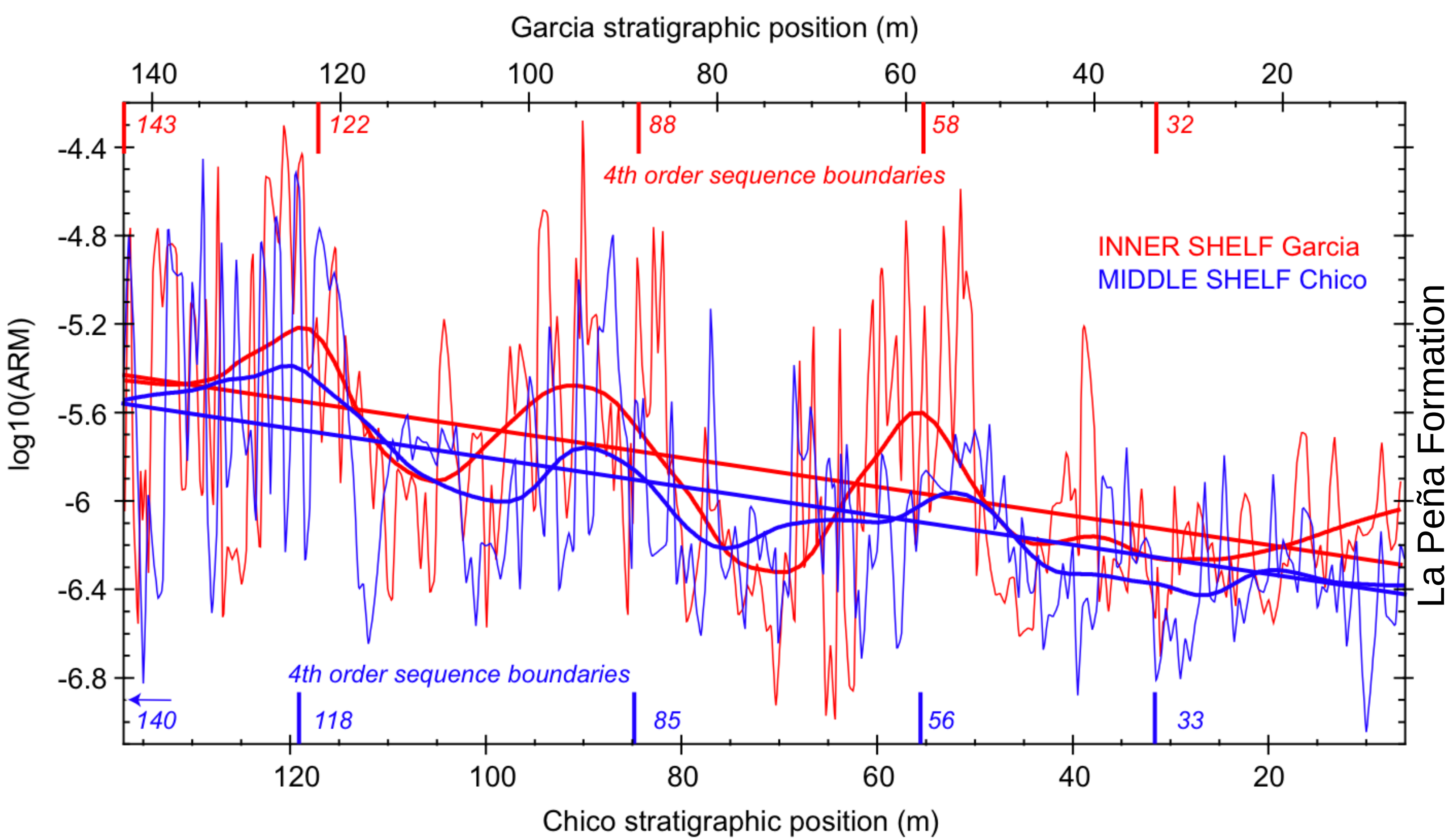
• Milankovitch-controlled paleoclimate signal

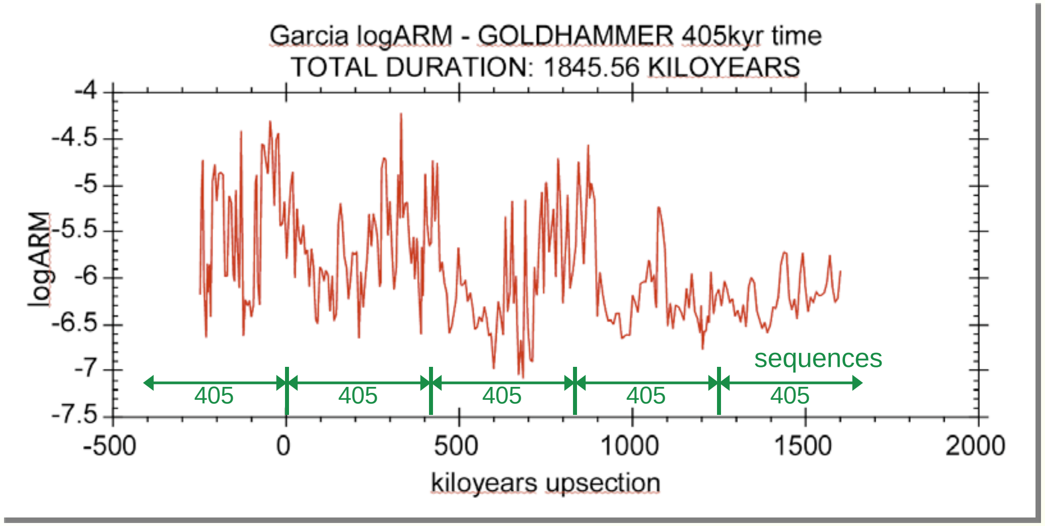
-ARM signature of long-term climate change



- Same linear decrease in sections, interpreted as decreasing dust deposition
- Global sea levels rising up-section; Cupido facies indicate progressive deepening
- Increasing humidity and/or higher sea levels explain systematic decline in dust deposition
- Both series have same long-period variation; maxima phased with sequence boundaries

• Milankovitch-controlled paleoclimate signal

-record of eccentricity, obliquity and precession index

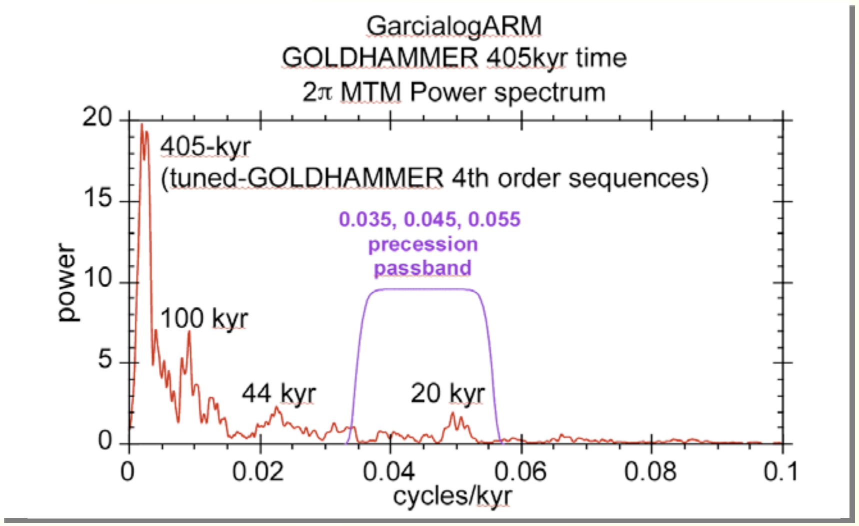


STEP 1

Set the Goldhammer sequence boundaries to 405-kyr time intervals (orbital eccentricity). Will other Milankovitch frequencies emerge?

Age model

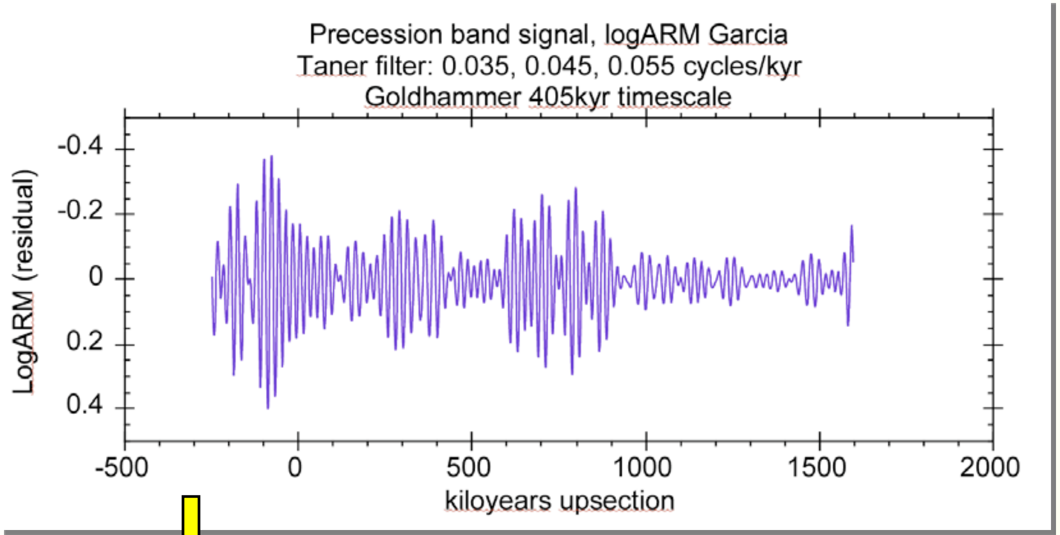
meter	kyrs
122	0
88	405
58	810
32	1215



Spectral analysis shows that 100-kyr eccentricity, obliquity, and precession band power are aligned by the tuning. Filter passband for the recovery of precession index (next step) is also shown.

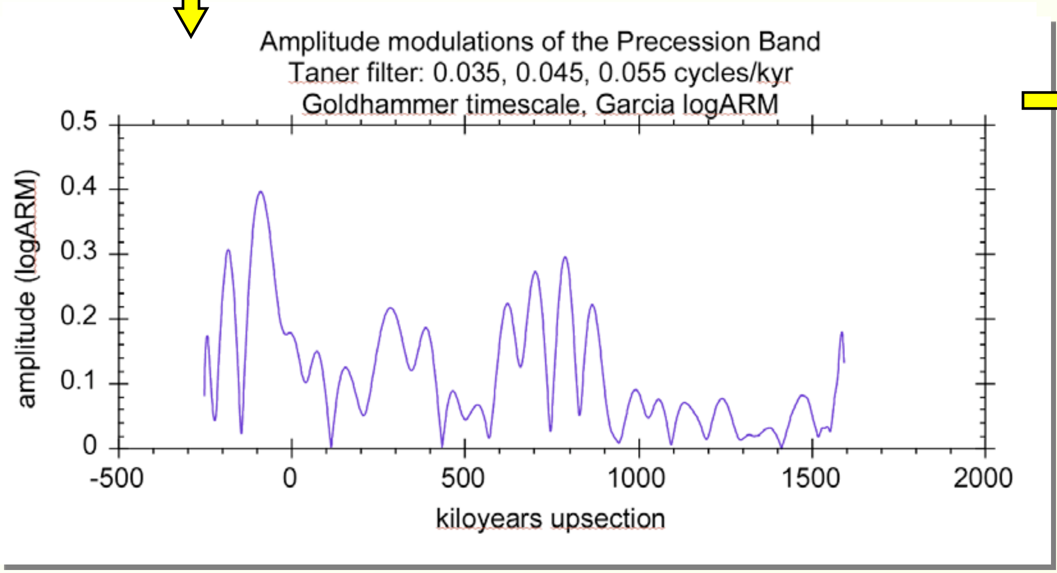
• Milankovitch-controlled paleoclimate signal

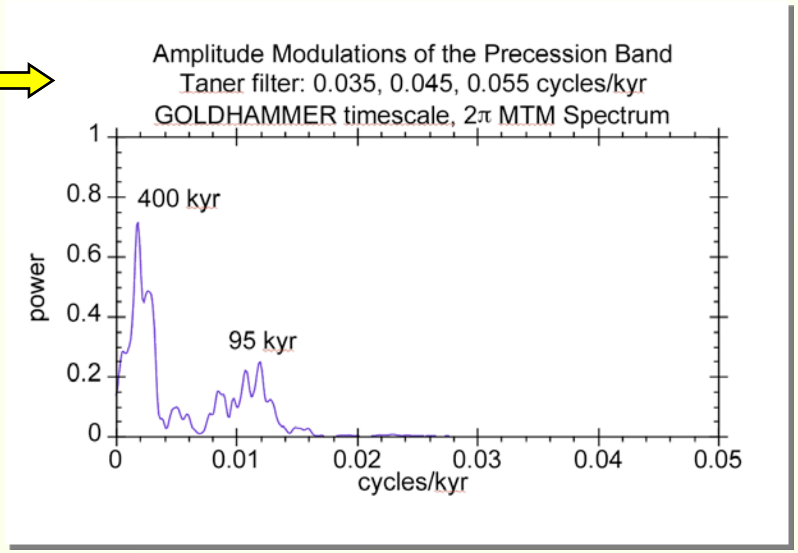
-record of eccentricity, obliquity and precession index



STEP 2

Does precession band signal have amplitude modulations demonstrating presence of orbital eccentricity? Filtered signal (upper left) subject to Hilbert transform (lower left), which has a spectrum (lower left) consistent with orbital eccentricity.





• Conclusions

SPECIFIC:

• ARM signal is synchronous between platform sites separated by ~30 km

• ARM signal is decoupled from fifth-order depositional cycles
  - suggests imperfect recording of Milankovitch-forced sea levels

• ARM amplitude weakens upsection as facies record deepening conditions
  - due to a warming, humid climate (less atmospheric dust)
  - changing global circulation (dust transported elsewhere)
  - greater dispersal of fine-grained magnetite in water column

GENERAL:

• ARM holds great promise in objective retrieval of paleoclimate signals
  - independent of host sediments/facies (carbonate)
  - proxy of highly sensitive parameter of global change (dust)

• ARM can contribute to ultra-high-resolution stratigraphic correlation

• ARM signals with high-fidelity Milankovitch frequencies can be used in construction of the Astronomical Time Scale.

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