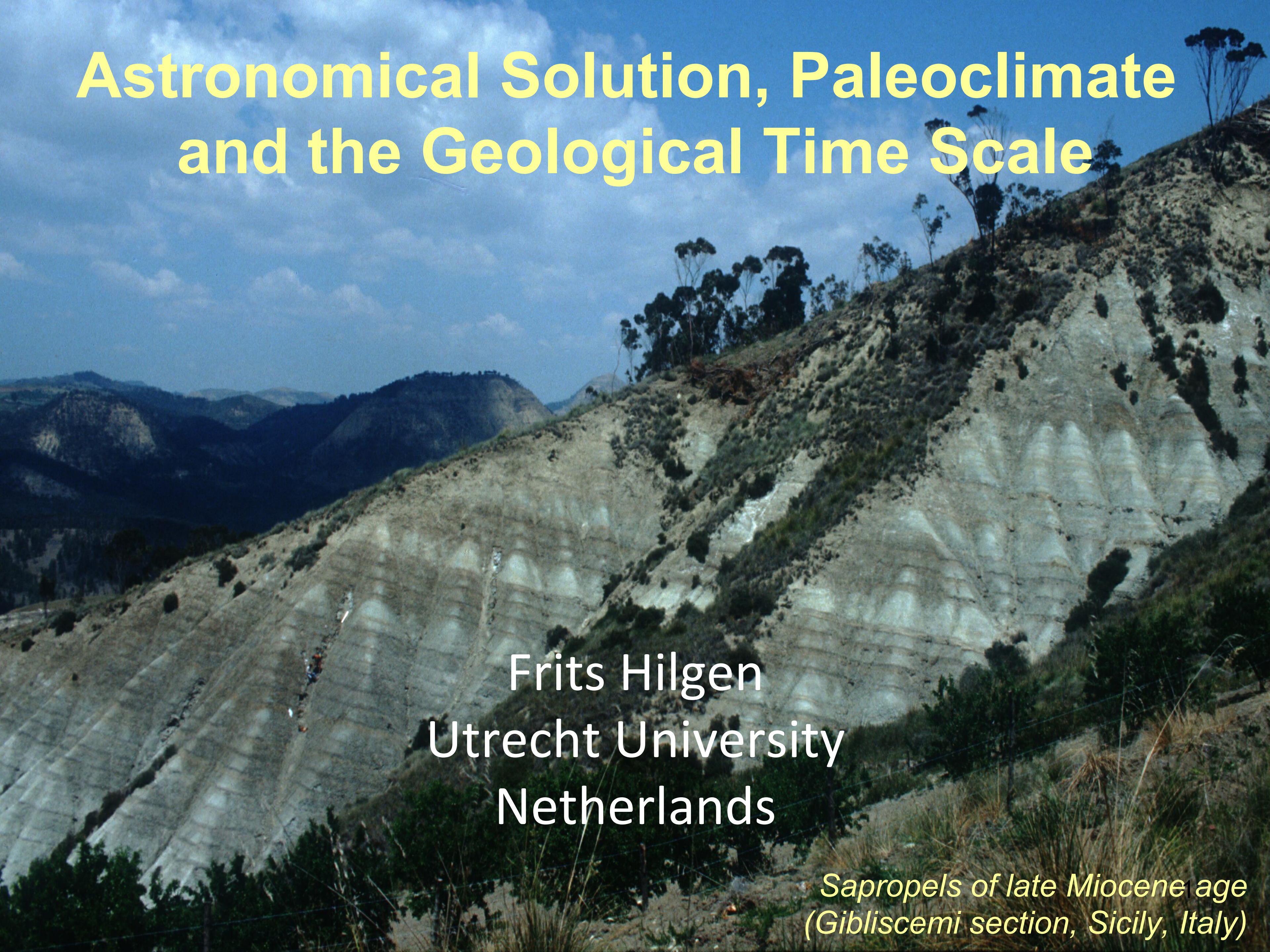
Astronomical Solution, Paleoclimate and the Geological Time Scale

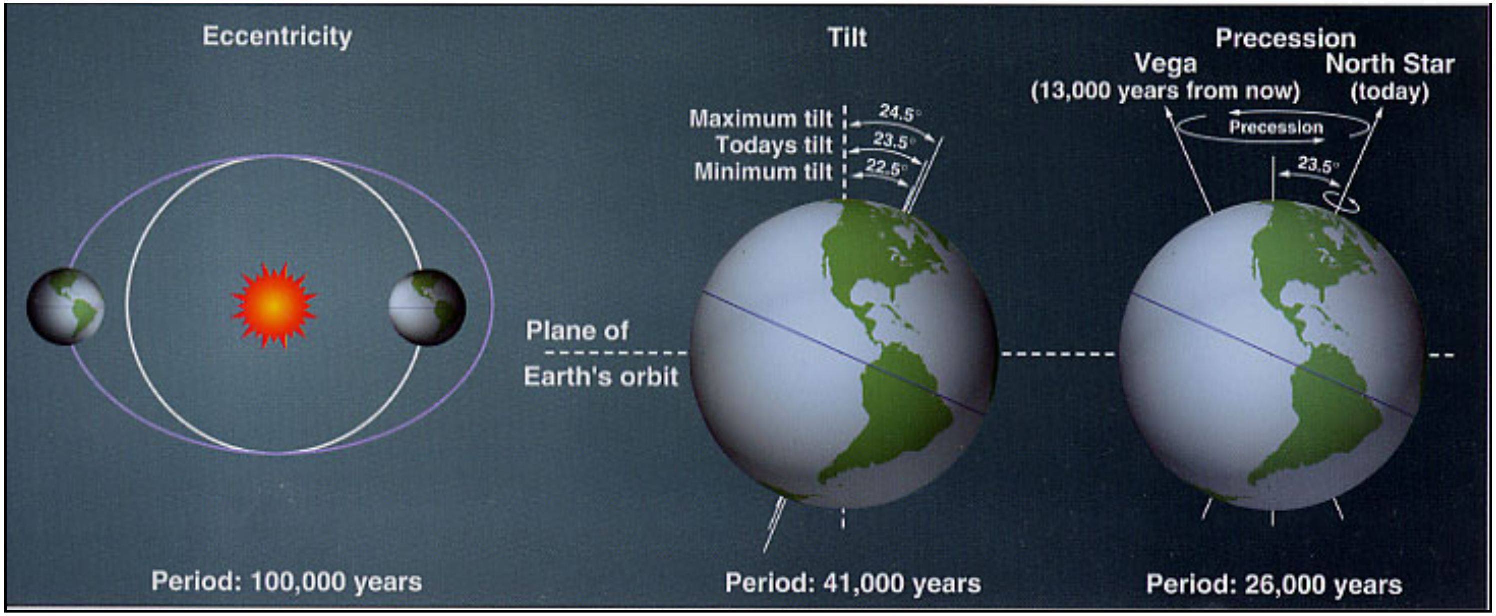
Frits Hilgen
Utrecht University
Netherlands



Sapropels of late Miocene age (Gibliscemi section, Sicily, Italy)

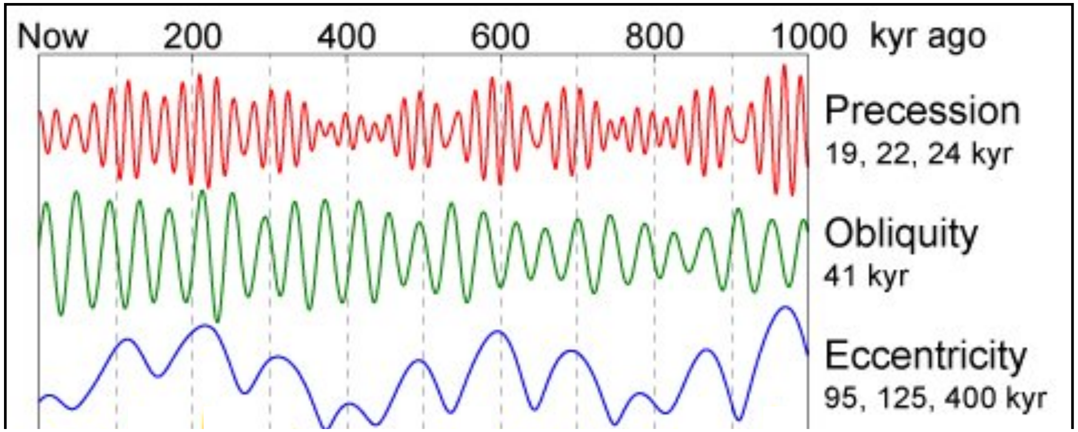

ELSEVIER
THE GEOLOGIC
TIME SCALE
2012
VOLUME 1
1. Astronomical dating & GTS
2. Paleoclimate & -modeling
3. Earth part of the solution
FELIX GRADSTEIN, JAMES OGG,
MARK SCHMITZ, AND GABI OGG

Earth's orbital and inclination cycles

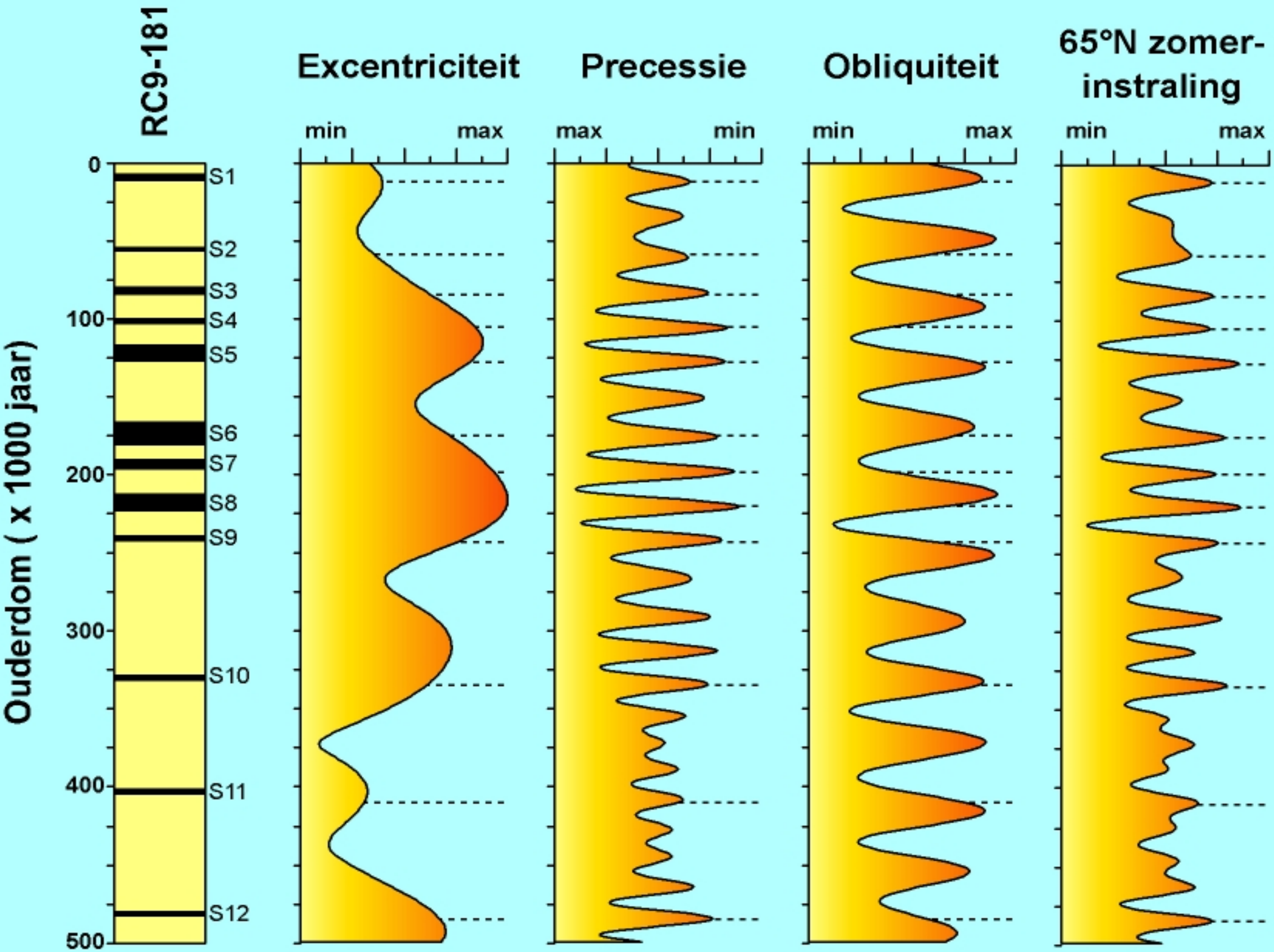


Precession, obliquity and eccentricity

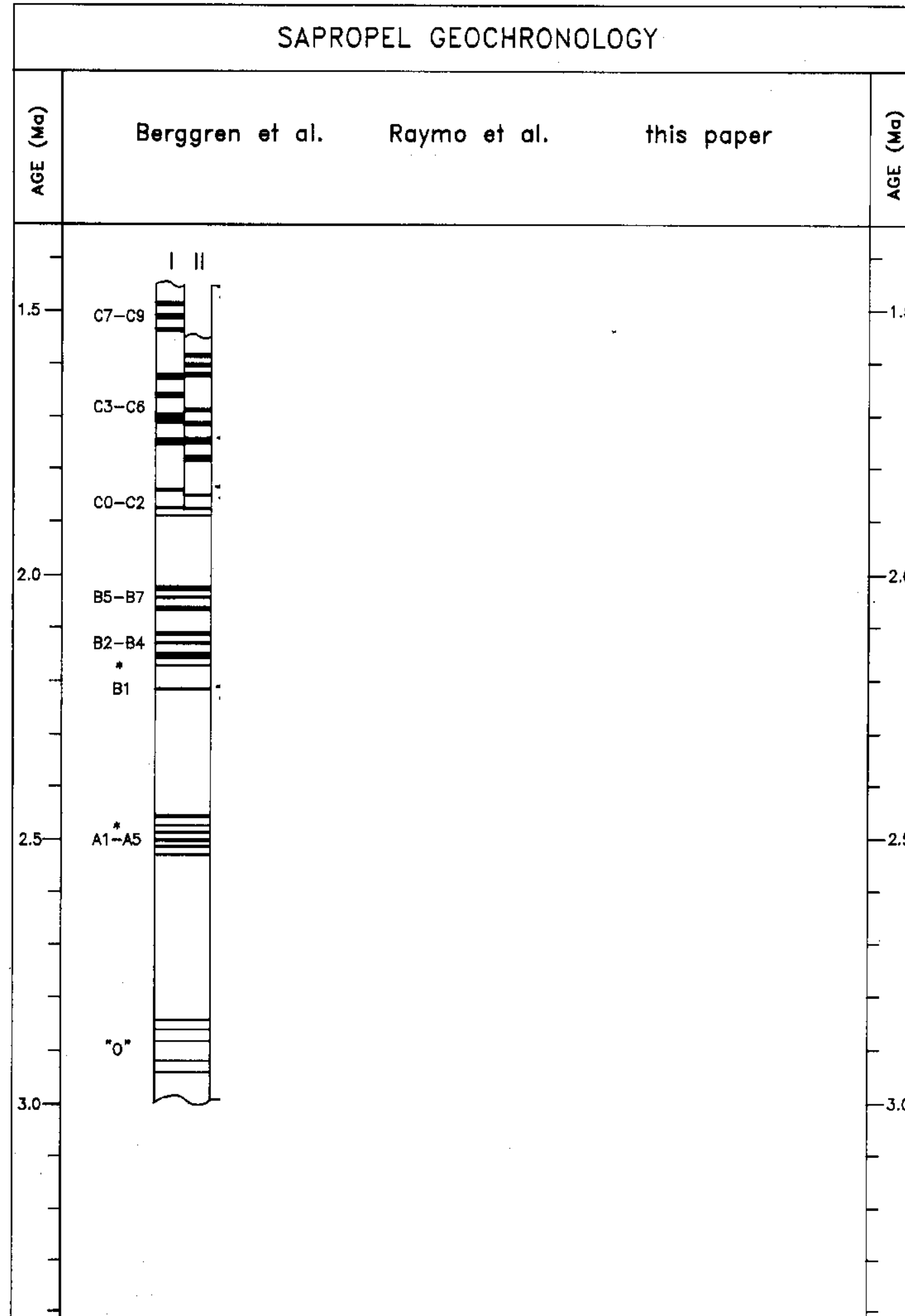
Astronomical dating



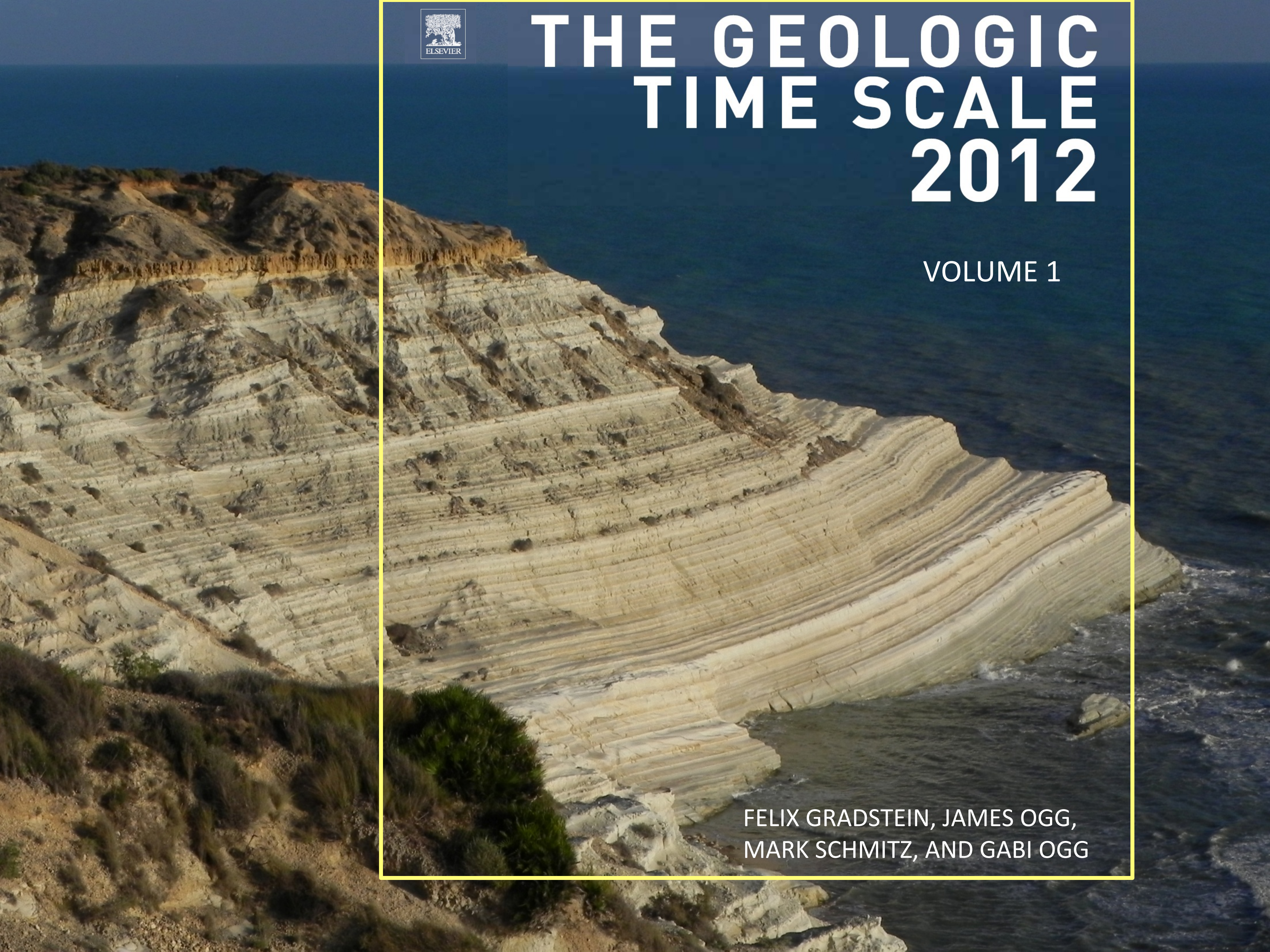
orbital phase relations



Astronomical tuning of sapropels



Singa & Rossello section



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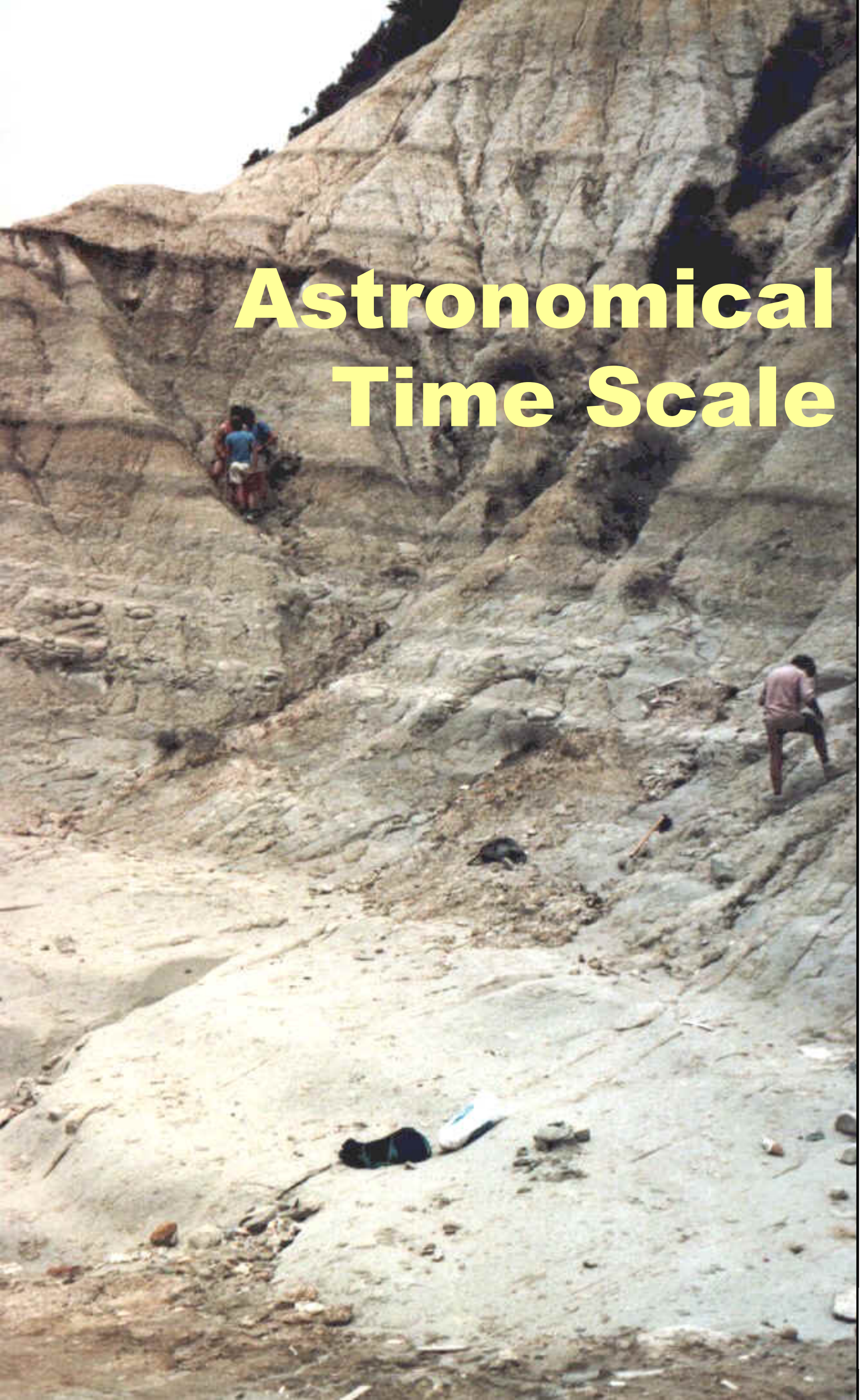
THE GEOLOGIC TIME SCALE 2012

VOLUME 1

FELIX GRADSTEIN, JAMES OGG,
MARK SCHMITZ, AND GABI OGG


Astronomical
Time Scale

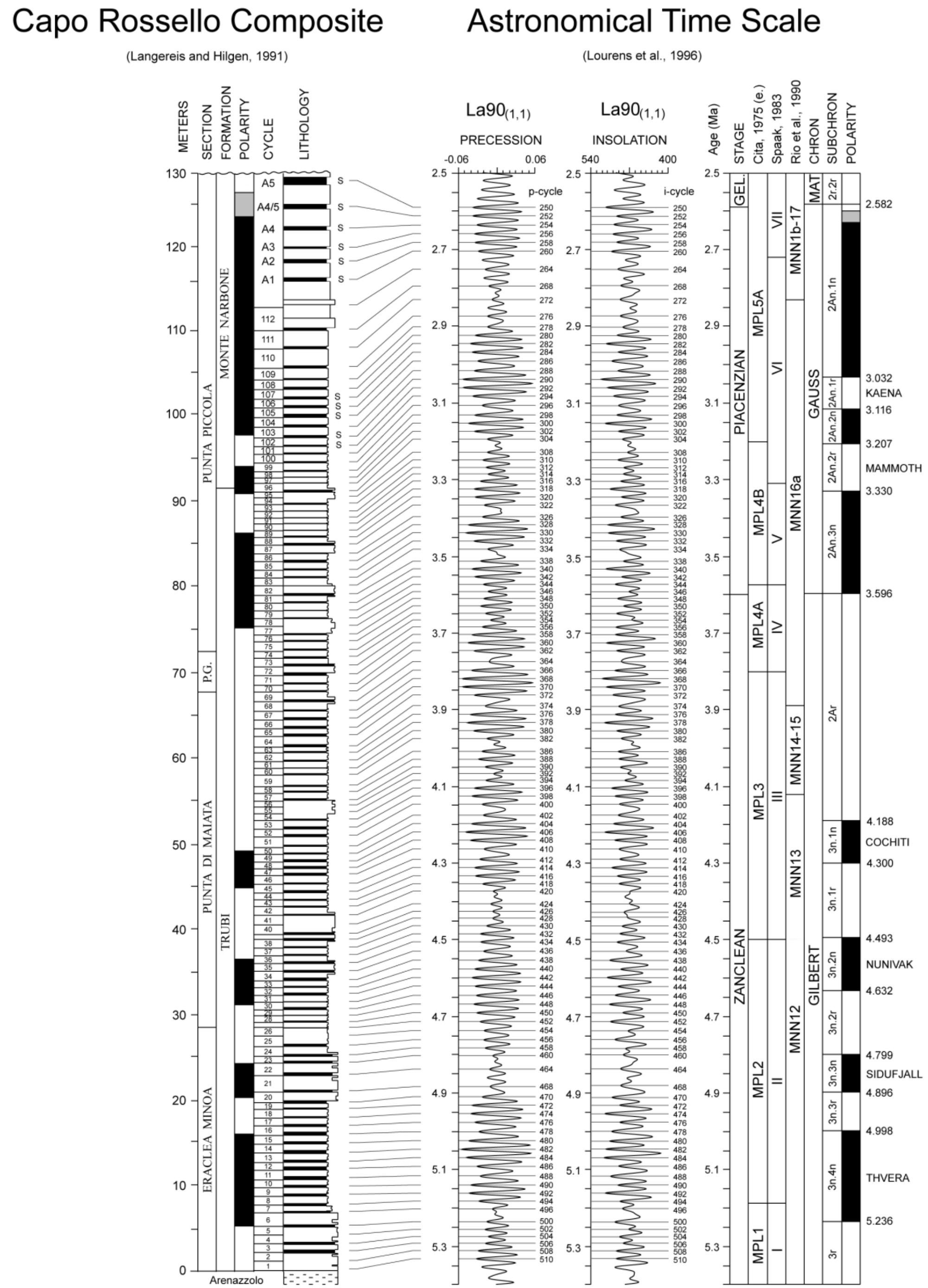

Capo Rossello Composite
(Langereis and Hilgen, 1991)
Astronomical Time Scale
(Lourens et al., 1996)
METERS
SECTION
FORMATION
POLARITY
CYCLE
LITHOLOGY
MONTE NARBONE
PUNTA PICCOLA
P.G.
PUNTA DI MAIATA
TRUBI
ERACLEA MINOA
Arenazzolo
La90(1,1)
PRECESSION
p-cycle
La90(1,1)
INSOLATION
i-cycle
Age (Ma)
STAGE
Cita, 1975 (e.)
Spaak, 1983
Rio et al., 1990
CHRON
SUBCHRON
POLARITY
GEL.
PIACENZIAN
ZANCLEAN
MPL5A
MPL4B
MPL4A
MPL3
MPL2
MPL1
MNN1b-17
MNN16a
MNN14-15
MNN13
MNN12
MAT
GAUSS
GILBERT
2.582
3.032
KAENA
3.116
3.207
MAMMOTH
3.330
3.596
4.188
COCHITI
4.300
4.493
NUNIVAK
4.632
4.799
SIDUFJALL
4.896
4.998
THVERA
5.236

FIGURE 1

INTERNATIONAL STRATIGRAPHIC CHART

ICS

International Commission on Stratigraphy

IUGS

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
Phanerozoic	Cenozoic	Quaternary	Holocene		0.0117	GSSP
			Pleistocene	Upper	0.126	
				"Ionian"	0.781	
				Calabrian	1.806	GSSP
				Gelasian	2.588	GSSP
		Neogene	Pliocene	Piacenzian	3.600	GSSP
				Zanclean	5.332	GSSP
			Miocene	Messinian	7.246	GSSP
				Tortonian	11.608	GSSP
				Serravallian	13.82	GSSP
				Langhian	15.97	
				Burdigalian	20.43	
				Aquitanian	23.03	GSSP
		Paleogene	Oligocene	Chattian	28.4 ±0.1	
				Rupelian	33.9 ±0.1	GSSP
			Eocene	Priabonian	37.2 ±0.1	
				Bartonian	40.4 ±0.2	
				Lutetian	48.6 ±0.2	
				Ypresian	55.8 ±0.2	GSSP
			Paleocene	Thanetian	58.7 ±0.2	GSSP
				Selandian	~ 61.1	GSSP
				Danian	65.5 ±0.3	GSSP
	Mesozoic	Cretaceous	Upper	Maastrichtian	70.6 ±0.6	GSSP
				Campanian	83.5 ±0.7	
				Santonian	85.8 ±0.7	
				Coniacian	~ 88.6	
				Turonian	93.6 ±0.8	GSSP
				Cenomanian	99.6 ±0.9	GSSP
			Lower	Albian	112.0 ±1.0	
				Aptian	125.0 ±1.0	
				Barremian	130.0 ±1.5	
				Hauterivian	~ 133.9	
				Valanginian	140.2 ±3.0	
				Berriasian	145.5 ±4.0	

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
					145.5 ±4.0	
Phanerozoic	Mesozoic	Jurassic	Upper	Tithonian	150.8 ±4.0	
				Kimmeridgian	~ 155.6	
				Oxfordian	161.2 ±4.0	
			Middle	Callovian	164.7 ±4.0	
				Bathonian	167.7 ±3.5	GSSP
				Bajocian	171.6 ±3.0	GSSP
				Aalenian	175.6 ±2.0	GSSP
			Lower	Toarcian	183.0 ±1.5	
				Pliensbachian	189.6 ±1.5	GSSP
				Sinemurian	196.5 ±1.0	GSSP
				Hettangian	199.6 ±0.6	
		Triassic	Upper	Rhaetian	203.6 ±1.5	
				Norian	216.5 ±2.0	
				Carnian	~ 228.7	GSSP
			Middle	Ladinian	237.0 ±2.0	GSSP
				Anisian	~ 245.9	
			Lower	Olenekian	~ 249.5	
				Induan	251.0 ±0.4	GSSP
	Paleozoic	Permian	Lopingian	Changhsingian	253.8 ±0.7	GSSP
				Wuchiapingian	260.4 ±0.7	GSSP
			Guadalupian	Capitanian	265.8 ±0.7	GSSP
				Wordian	268.0 ±0.7	GSSP
				Roadian	270.6 ±0.7	GSSP
			Cisuralian	Kungurian	275.6 ±0.7	
				Artinskian	284.4 ±0.7	
				Sakmarian	294.6 ±0.8	
				Asselian	299.0 ±0.8	GSSP
		Carboniferous	Pennsylvanian Upper	Gzhelian	303.4 ±0.9	
				Kasimovian	307.2 ±1.0	
			Pennsylvanian Middle	Moscovian	311.7 ±1.1	
			Pennsylvanian Lower	Bashkirian	318.1 ±1.3	GSSP
			Mississippian Upper	Serpukhovian	328.3 ±1.6	
			Mississippian Middle	Visean	345.3 ±2.1	GSSP
			Mississippian Lower	Tournaisian	359.2 ±2.5	GSSP

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
					359.2 ±2.5	
Phanerozoic	Paleozoic	Devonian	Upper	Famennian	374.5 ±2.6	GSSP
				Frasnian	385.3 ±2.6	GSSP
			Middle	Givetian	391.8 ±2.7	GSSP
				Eifelian	397.5 ±2.7	GSSP
			Lower	Emsian	407.0 ±2.8	GSSP
				Pragian	411.2 ±2.8	GSSP
				Lochkovian	416.0 ±2.8	GSSP
		Silurian	Pridoli		418.7 ±2.7	GSSP
			Ludlow	Ludfordian	421.3 ±2.6	GSSP
				Gorstian	422.9 ±2.5	GSSP
			Wenlock	Homerian	426.2 ±2.4	GSSP
				Sheinwoodian	428.2 ±2.3	GSSP
			Llandovery	Telychian	436.0 ±1.9	GSSP
				Aeronian	439.0 ±1.8	GSSP
				Rhuddanian	443.7 ±1.5	GSSP
		Ordovician	Upper	Hirnantian	445.6 ±1.5	GSSP
				Katian	455.8 ±1.6	GSSP
				Sandbian	460.9 ±1.6	GSSP
			Middle	Darriwilian	468.1 ±1.6	GSSP
				Dapingian	471.8 ±1.6	GSSP
			Lower	Floian	478.6 ±1.7	GSSP
				Tremadocian	488.3 ±1.7	GSSP
		Cambrian	Furongian	*Stage 10*	~ 492 *	
				Stage 9	~ 496 *	
				Paibian	~ 499	GSSP
			Series 3	Guzhangian	~ 503	GSSP
				Drumian	~ 506.5	GSSP
				Stage 5	~ 510 *	
			Series 2	*Stage 4*	~ 515 *	
				Stage 3	~ 521 *	
			Terreneuvian	*Stage 2*	~ 528 *	
				Fortunian	542.0 ±1.0	GSSP

	Eonothem Eon	Erathem Era	System Period	Age Ma	GSSP GSSA
				542	
Precambrian	Proterozoic	Neoproterozoic	Ediacaran	~635	GSSP
			Cryogenian	850	GSSA
			Tonian	1000	GSSA
		Mesoproterozoic	Stenian	1200	GSSA
			Ectasian	1400	GSSA
			Calymmian	1600	GSSA
		Paleoproterozoic	Statherian	1800	GSSA
			Orosirian	2050	GSSA
			Rhyacian	2300	GSSA
			Siderian	2500	GSSA
	Archean	Neoarchean		2800	GSSA
		Mesoarchean		3200	GSSA
		Paleoarchean		3600	GSSA
		Eoarchean		4000	
	Hadean (informal)			~4600	

Subdivisions of the global geologic record are formally defined by their lower boundary. Each unit of the Phanerozoic (~542 Ma to Present) and the base of Ediacaran are defined by a basal Global Boundary Stratotype Section and Point (GSSP), whereas Precambrian units are formally subdivided by absolute age (Global Standard Stratigraphic Age, GSSA). Details of each GSSP are posted on the ICS website (*www.stratigraphy.org*).

Numerical ages of the unit boundaries in the Phanerozoic are subject to revision. Some stages within the Cambrian will be formally named upon international agreement on their GSSP limits. Most sub-Series boundaries (e.g., Middle and Upper Aptian) are not formally defined.

Colors are according to the Commission for the Geological Map of the World (*www.cgmw.org*).

The listed numerical ages are from 'A Geologic Time Scale 2004', by F.M. Gradstein, J.G. Ogg, A.G. Smith, et al. (2004; Cambridge University Press) and "The Concise Geologic Time Scale" by J.G. Ogg, G. Ogg and F.M. Gradstein (2008).

This chart was drafted by Gabi Ogg. Intra Cambrian unit ages with * are informal, and awaiting ratified definitions.

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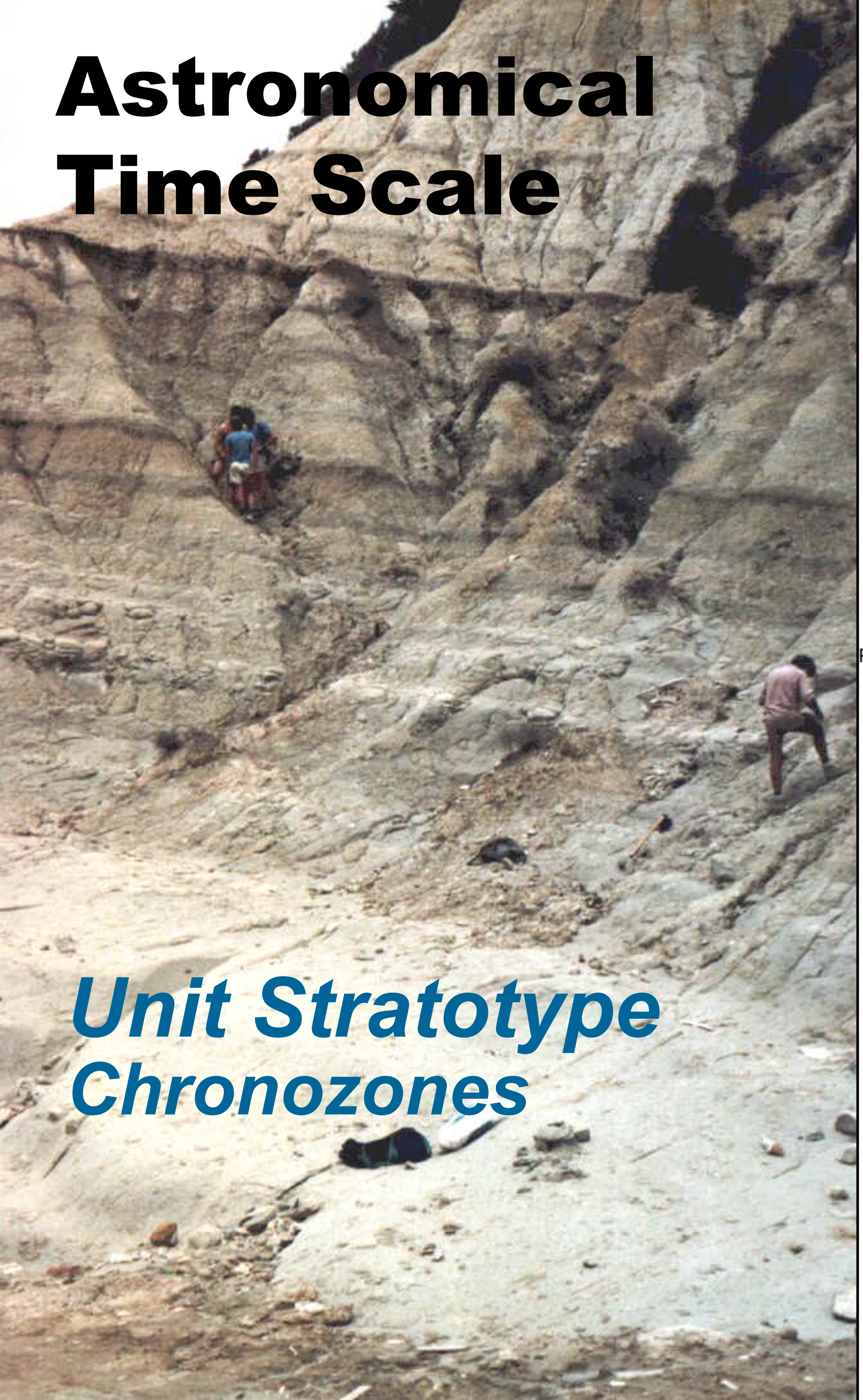
August 2009

Astronomical Time Scale



Unit Stratotype Chronozones

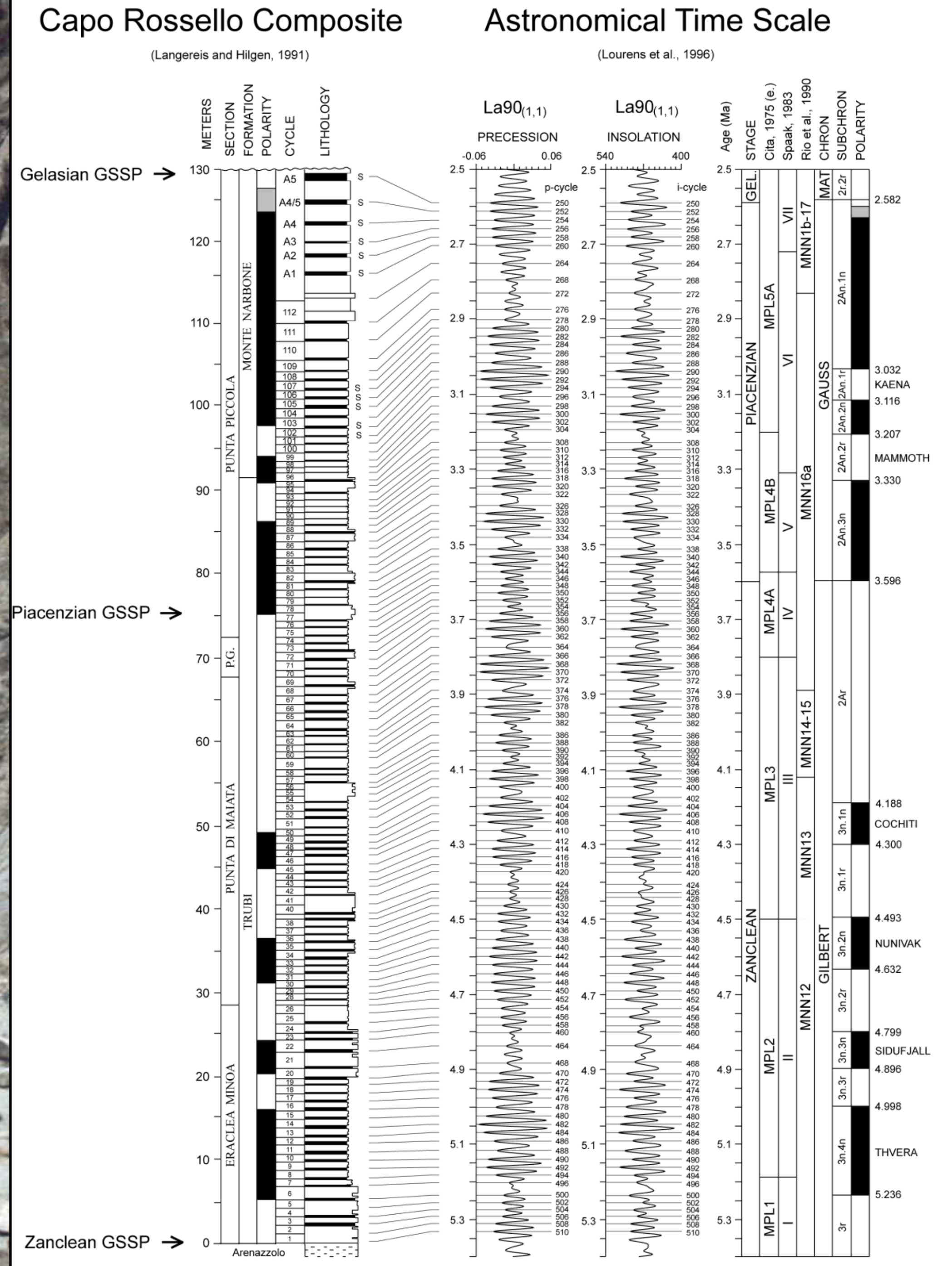
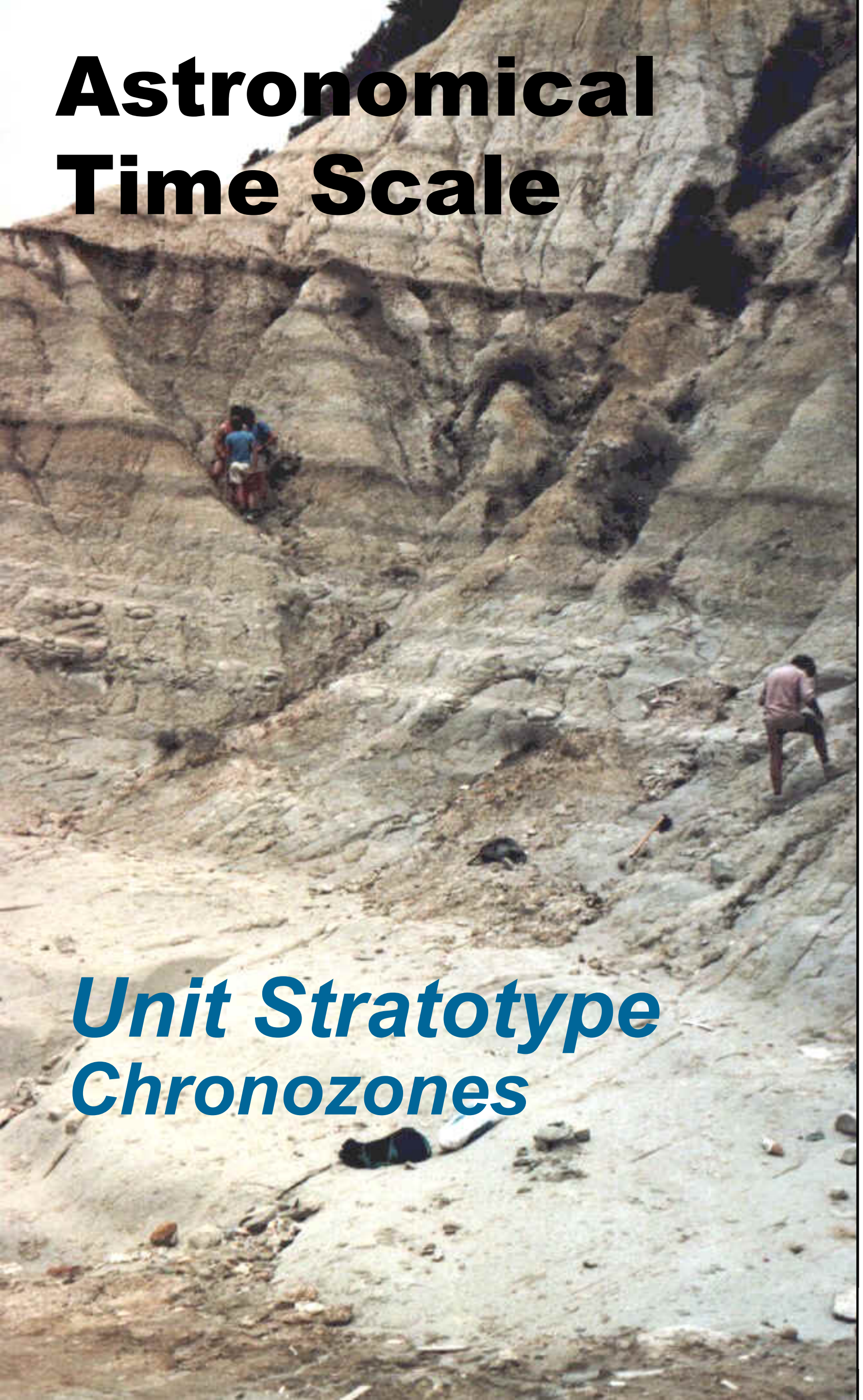


FIGURE 1


Astronomical
Time Scale
Unit Stratotype
Chronozones

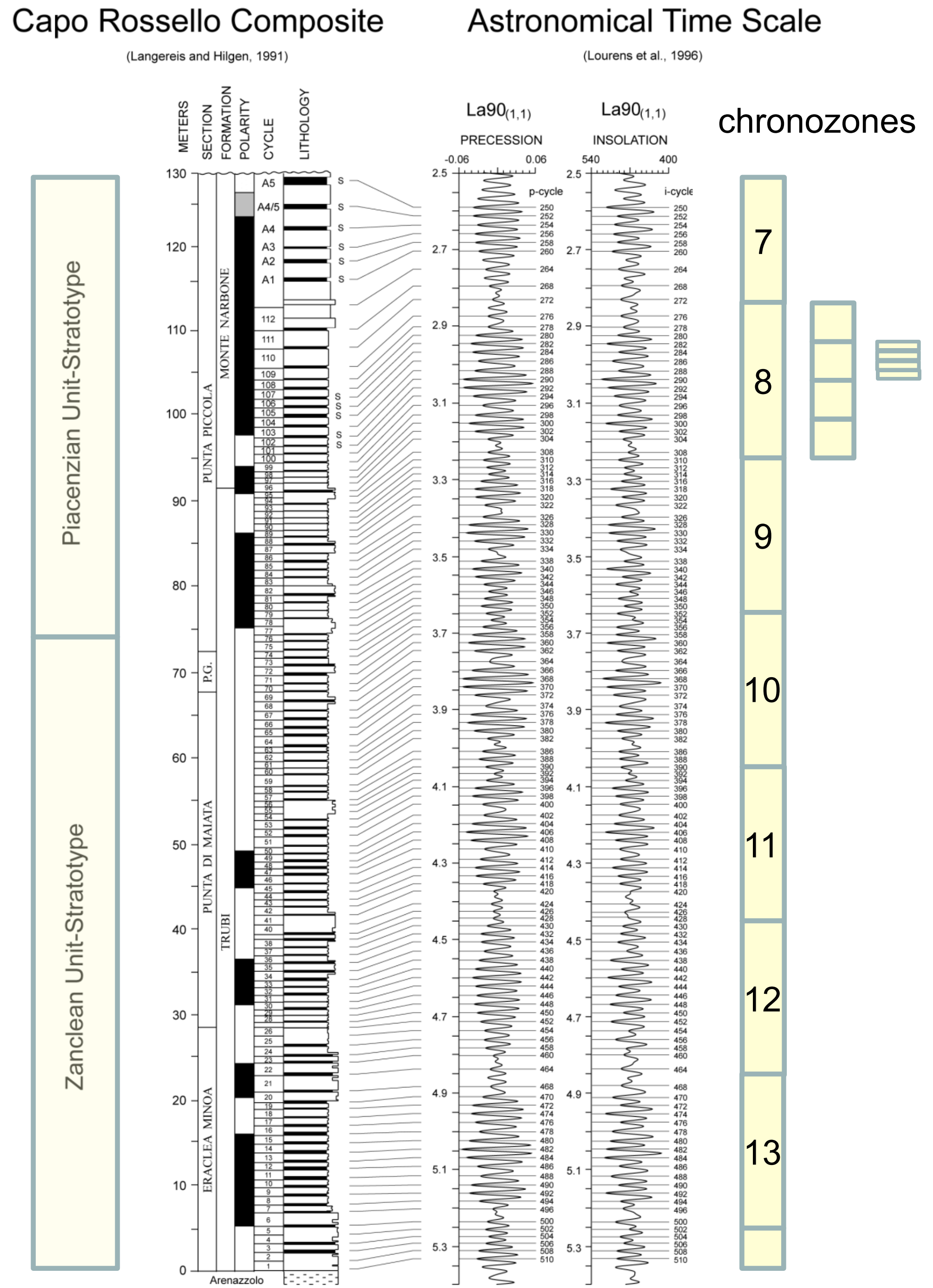
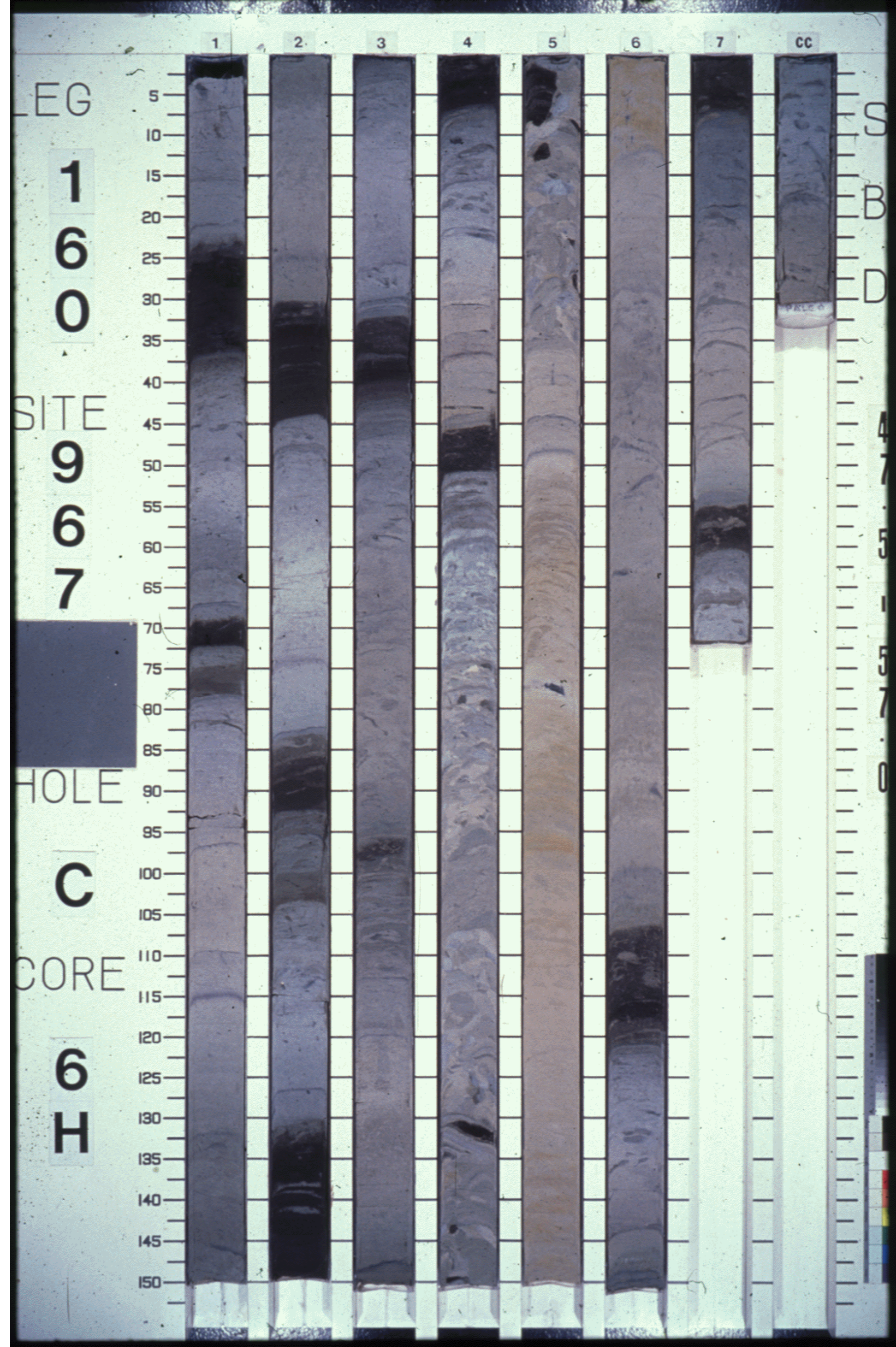
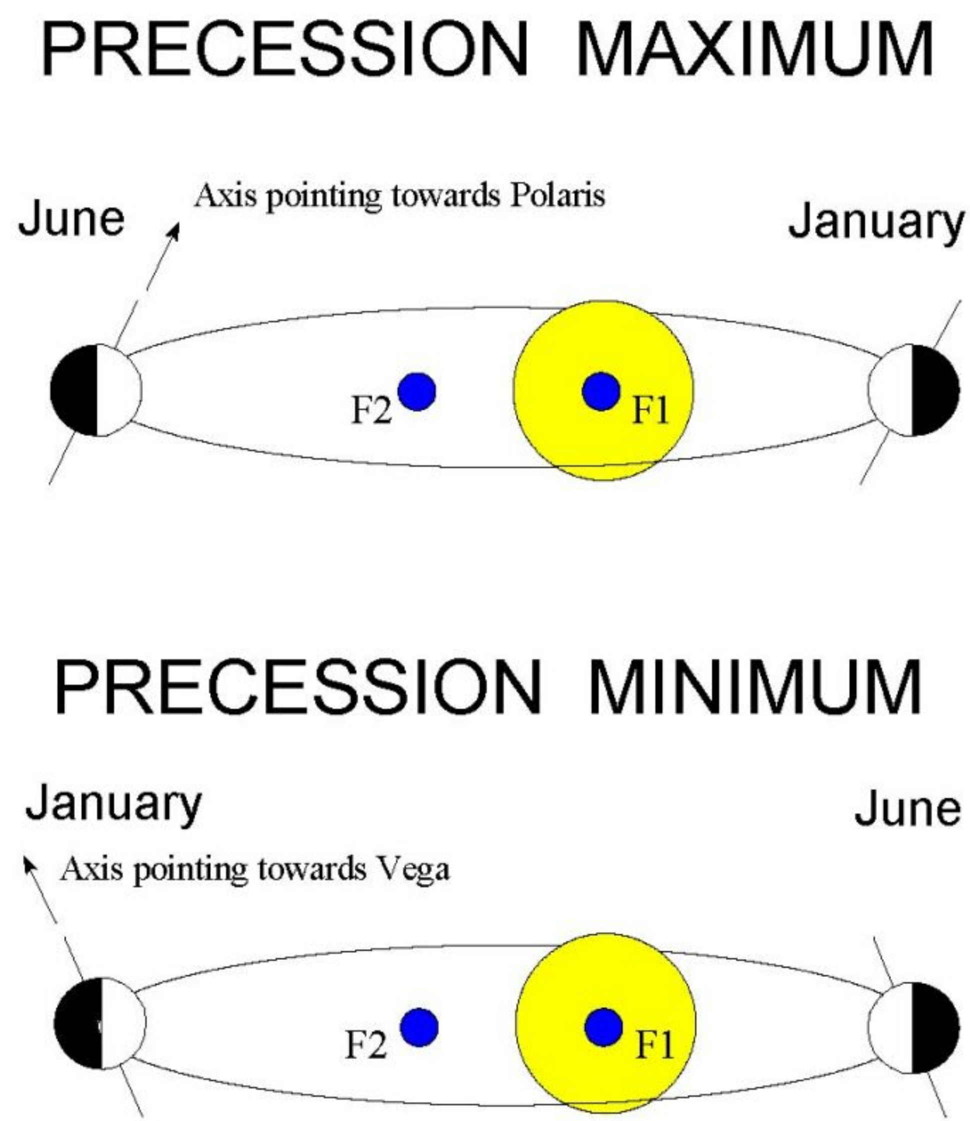

Capo Rossello Composite
(Langereis and Hilgen, 1991)
Astronomical Time Scale
(Lourens et al., 1996)
METERS
SECTION
FORMATION
POLARITY
CYCLE
LITHOLOGY
Piacenzian Unit-Stratotype
Zanclean Unit-Stratotype
MONTE NARBONE
PUNTA PICCOLA
P.G.
PUNTA DI MAIATA
TRUBI
ERACLEA MINOA
Arenazzolo
La90(1,1)
PRECESSION
p-cycle
La90(1,1)
INSOLATION
i-cycle
chronozones
7
8
9
10
11
12
13

FIGURE 1

ODP Leg 160



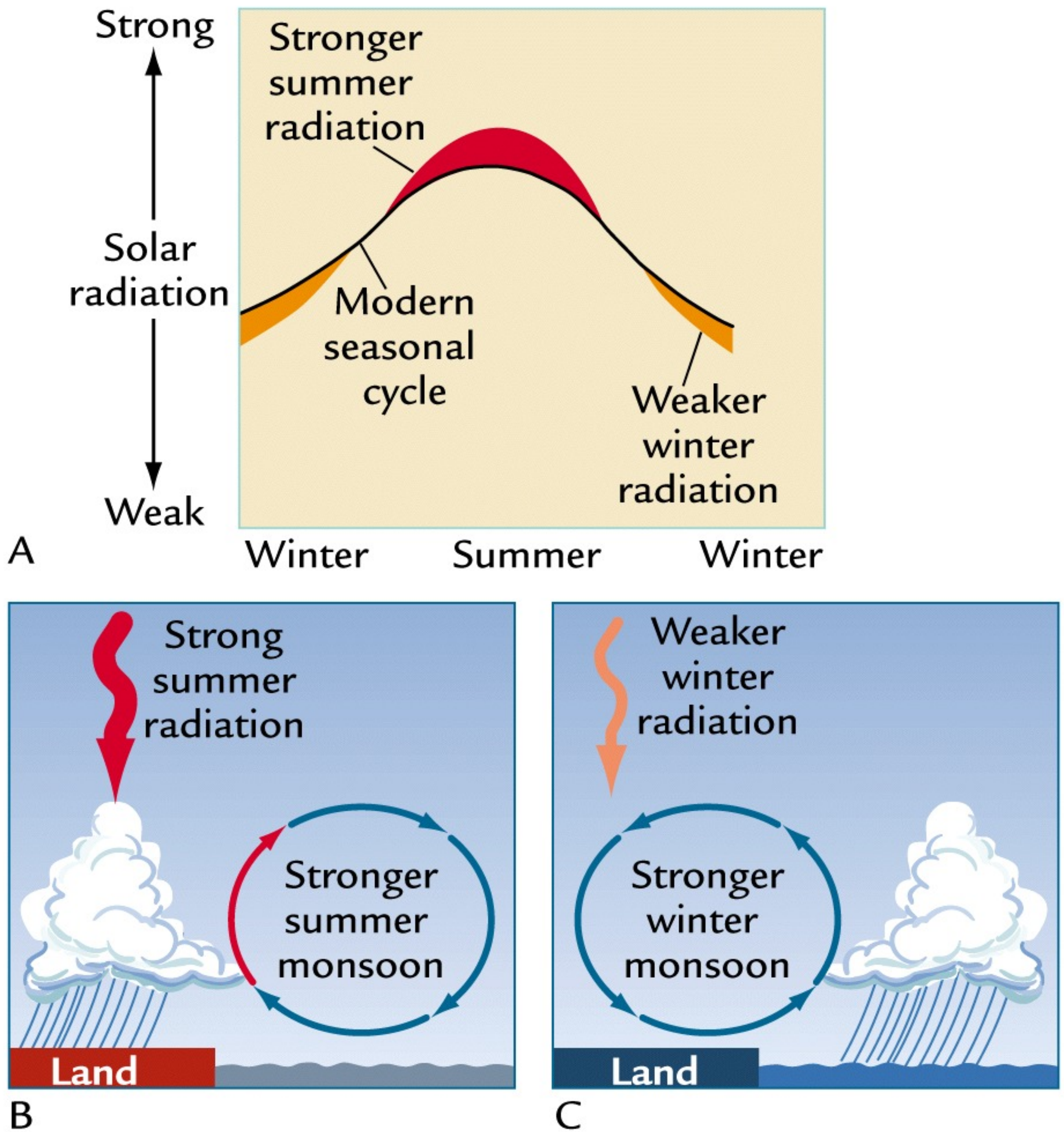
Climatic precession extremes



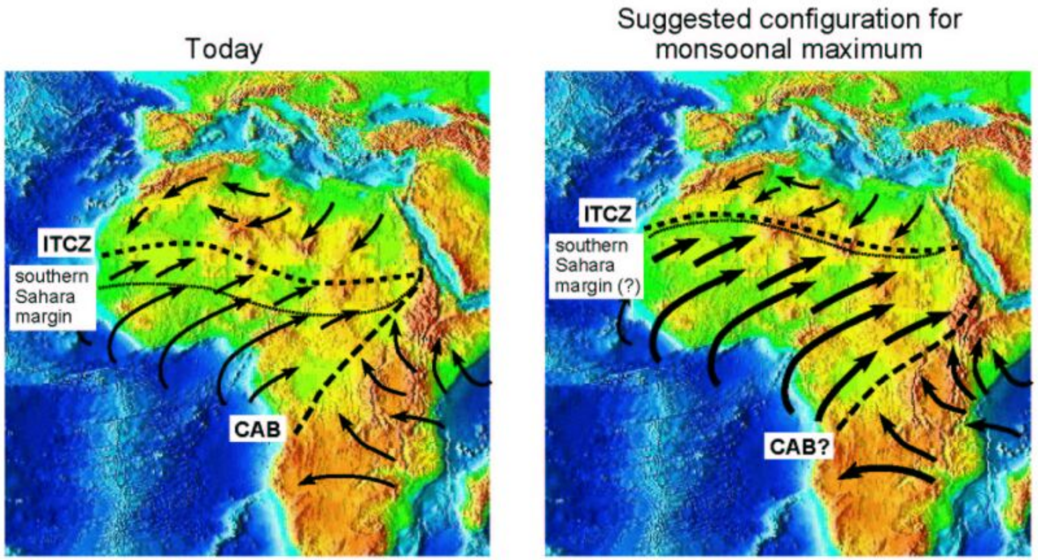
F1: focal point one of the elliptical orbit (sun)

F2: focal point two of the elliptical orbit (empty)

Orbital forcing of monsoons

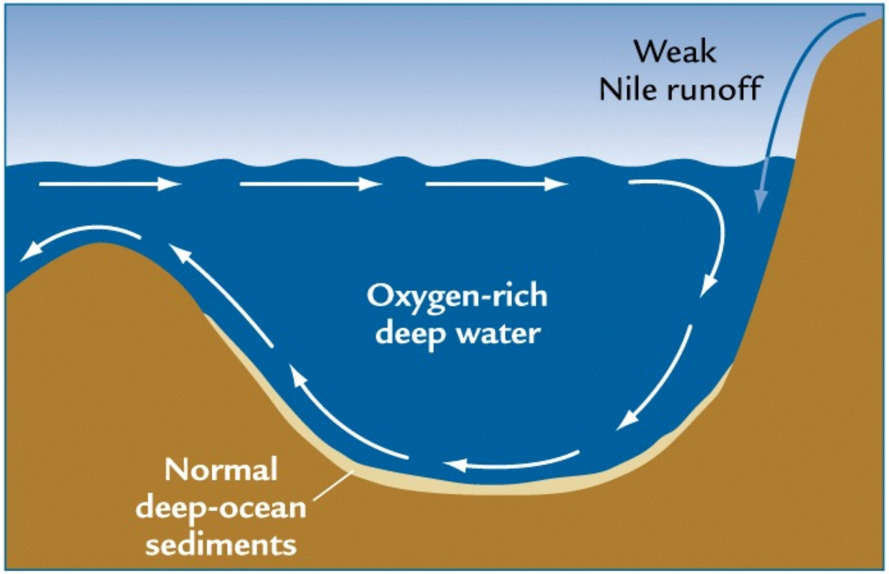


Insolation control of the Monsoon

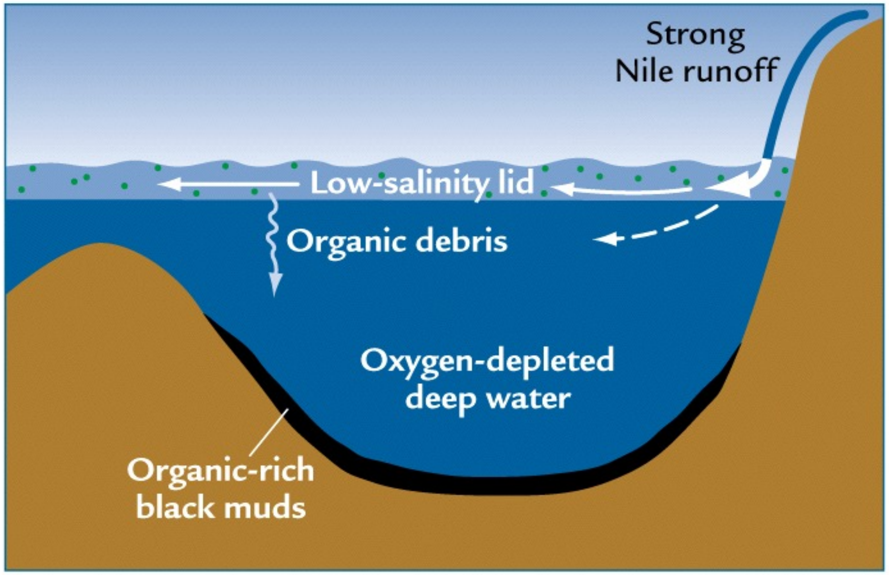


Precession influence on African Monsoon

Sapropel formation

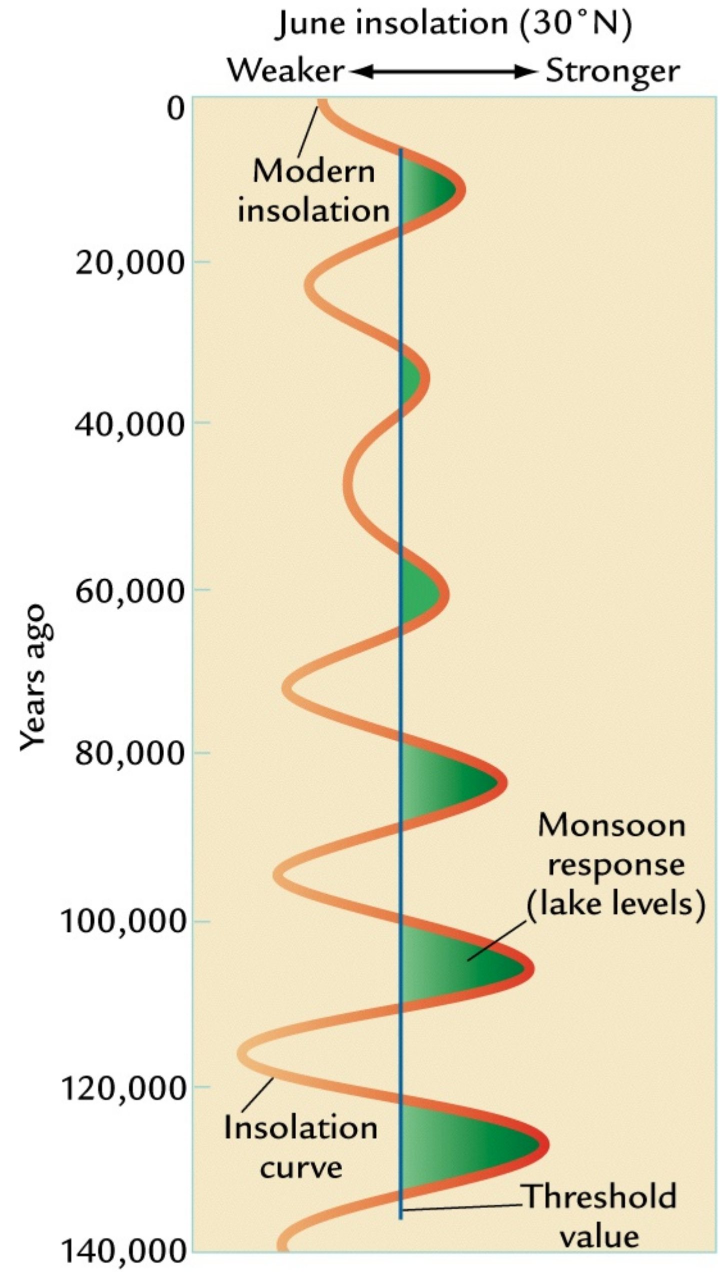


A Weak summer monsoon



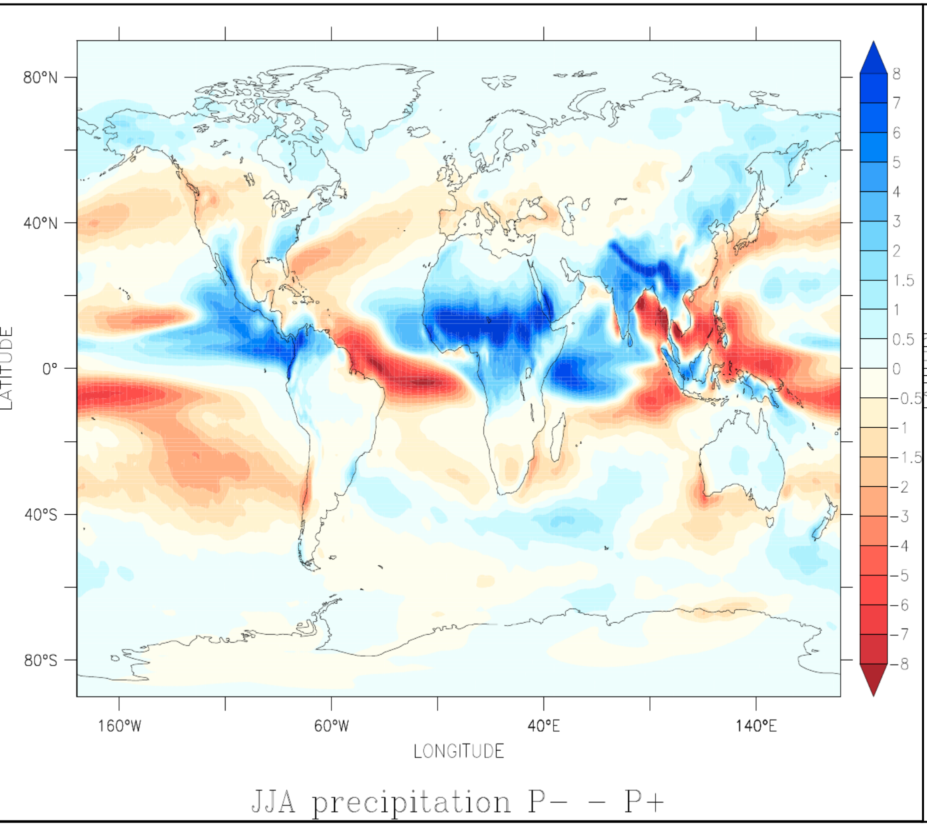
B Strong summer monsoon

Insolation control on monsoon

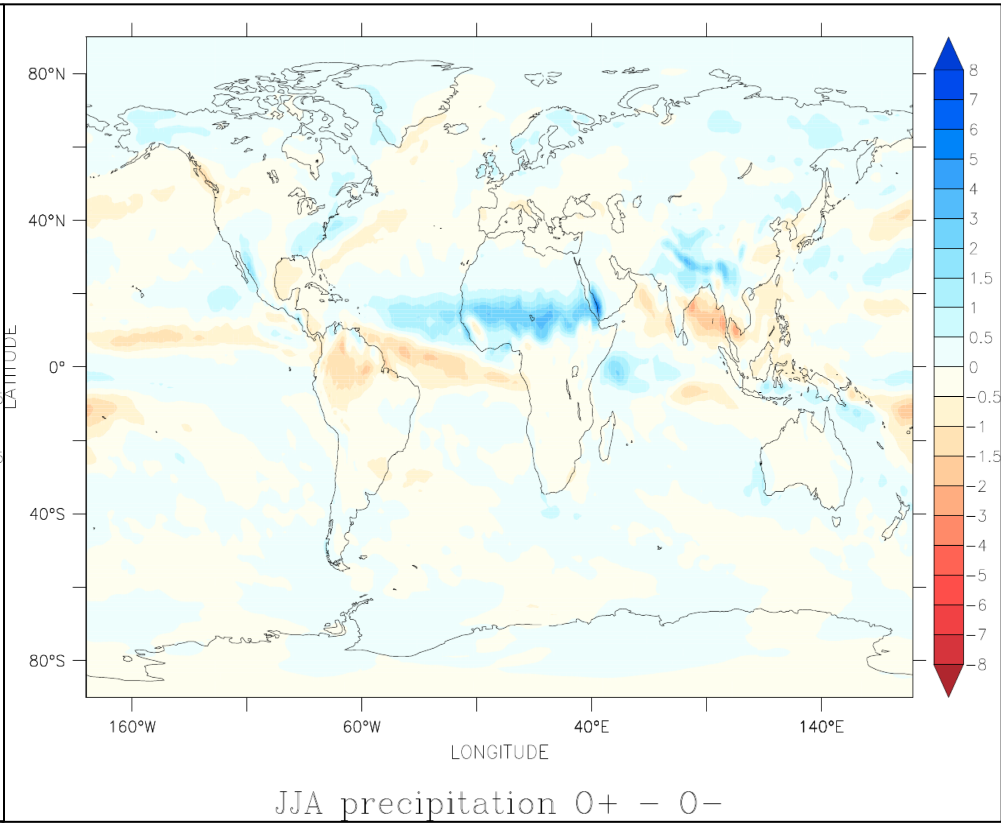


Climate modeling of orbital extremes (precipitation in mm/dag)

Pmin – Pmax JJA

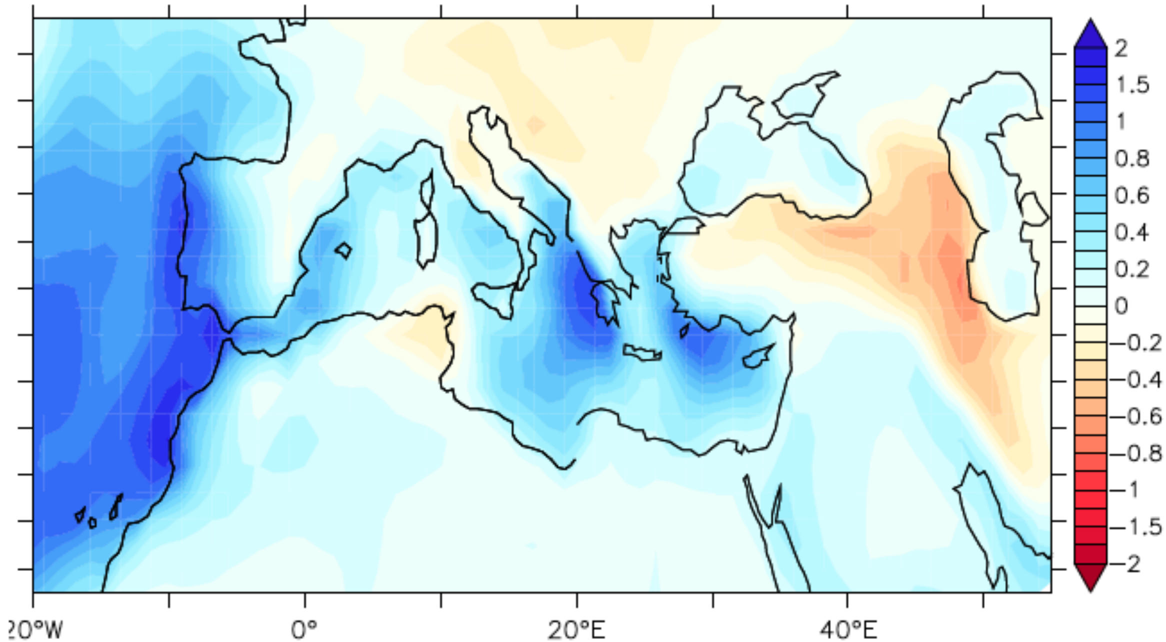


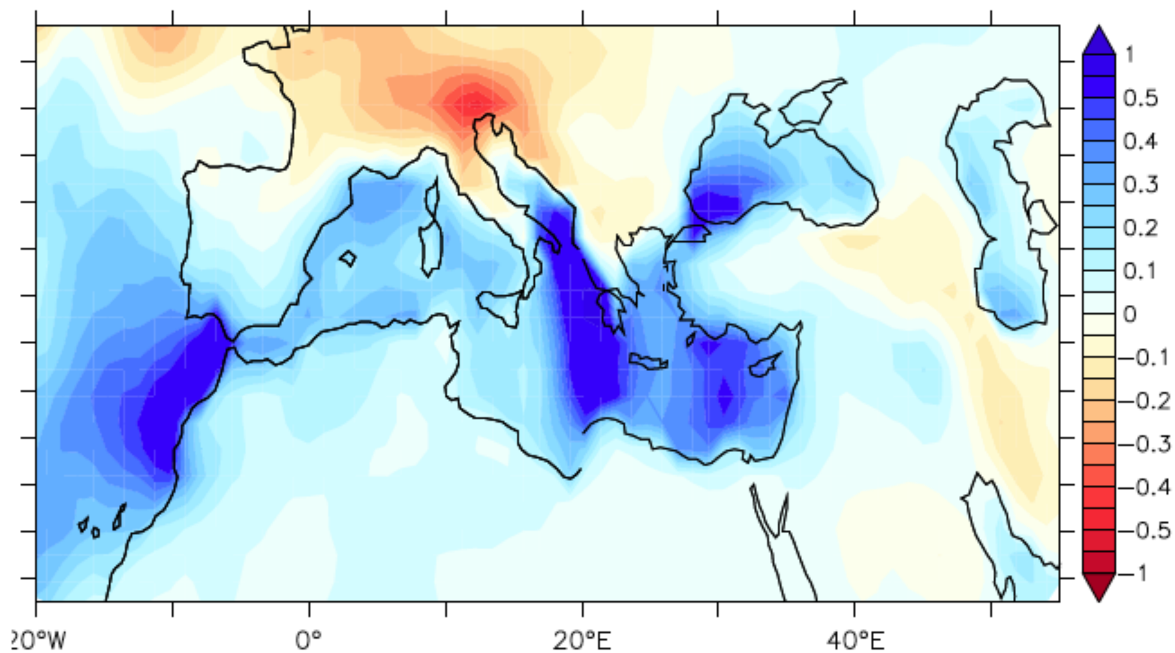
Tmax – Tmin JJA



Climate modeling of orbital extremes (precipitation in mm/dag)

Pmin – Pmax ONDJFM





Tmax – Tmin ONDJFM

Astronomical solution

- Part 1: Orbital part, solves planetary system, used to compute eccentricity
- Part 2: Earth-Moon part, solves the Earth-Moon system, used to compute precession and obliquity
- Part 3: Earth part, tidal dissipation and dynamical ellipticity, affect precession and obliquity

Astronomical Solution (La90-93)

Tidal Dissipation Term

- present = 1
- ice-age = 0 to 1

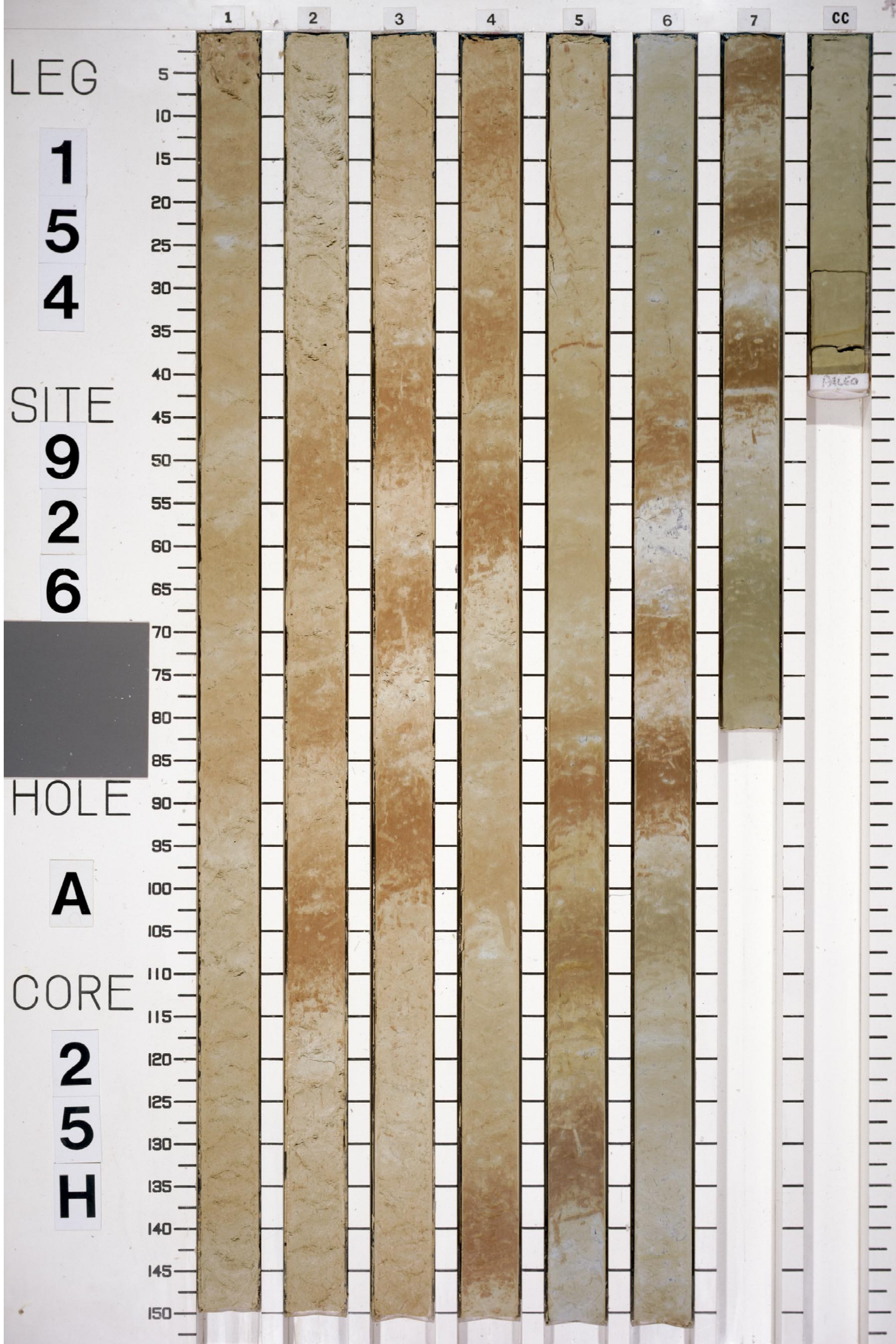
Dynamical ellipticity

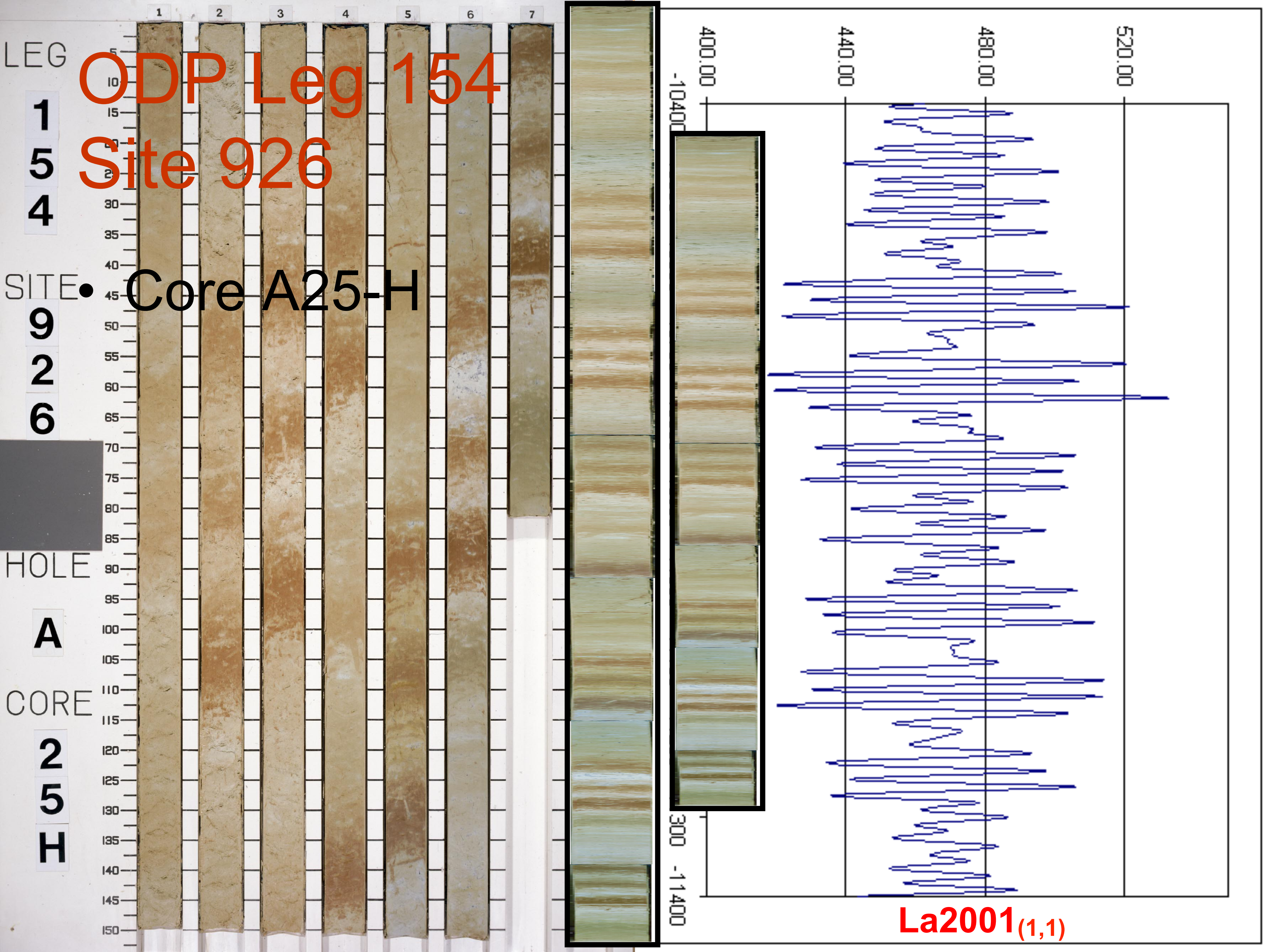
- present = 1
- ice-age < 1

These parameters both affect precession and obliquity and are added as suffix and between brackets to the solution, so $La90_{(1,1)}$

ODP Leg 154
Site 926

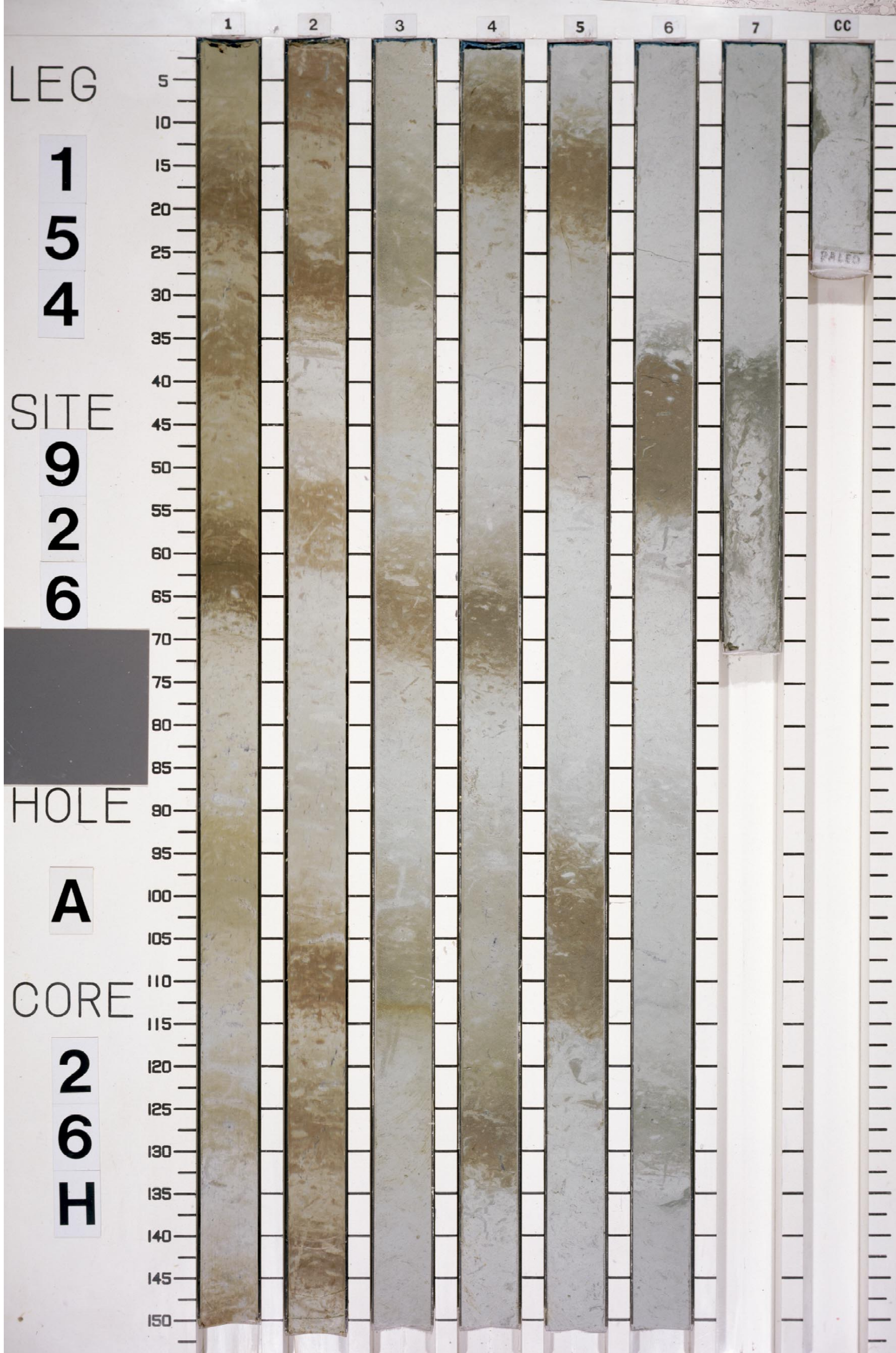
- Core A25-H

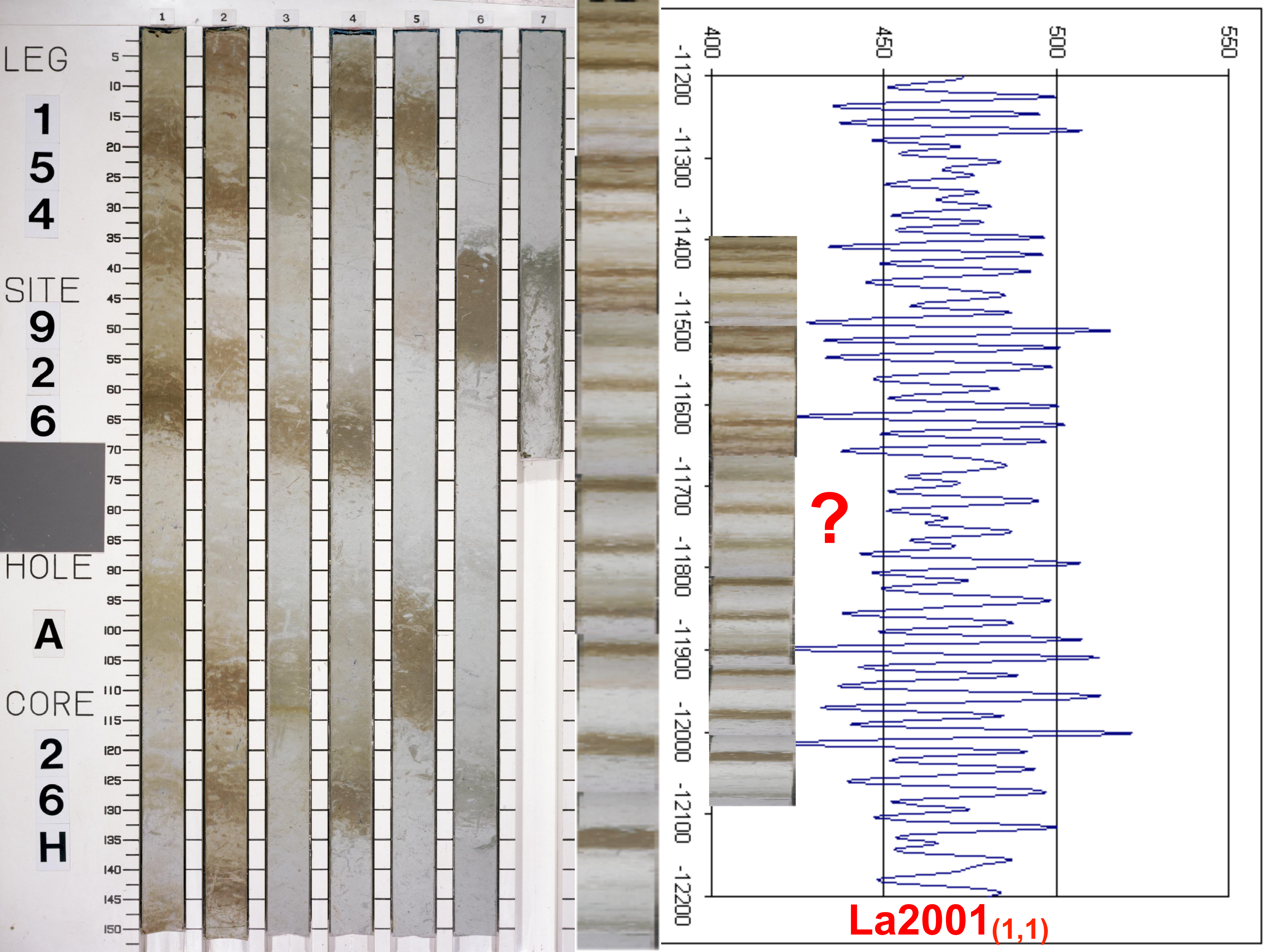


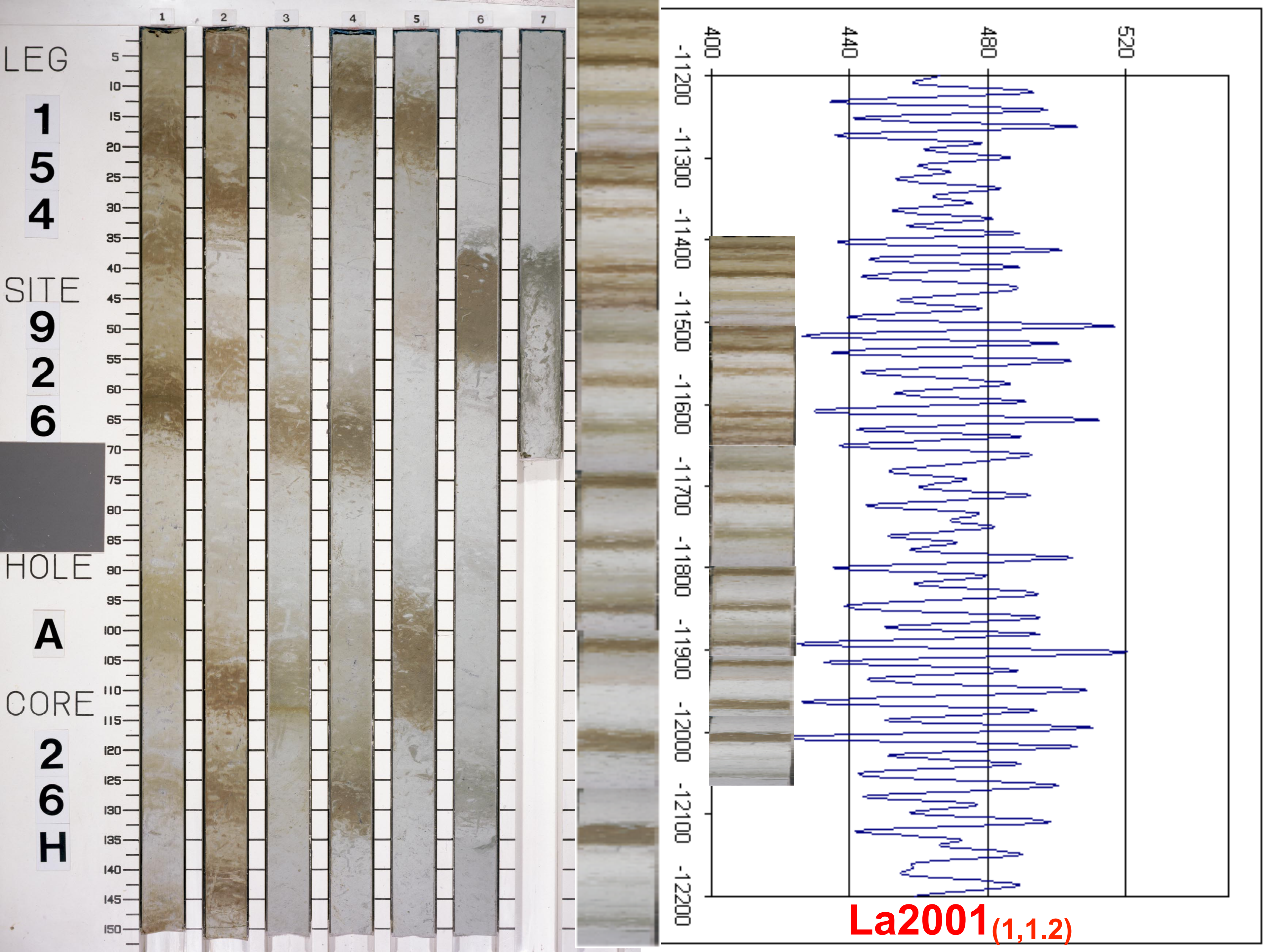

ODP Leg 154
Site 926
• Core A25-H
LEG
154
SITE
926
HOLE
A
CORE
25
H
1
2
3
4
5
6
7
400.00
440.00
480.00
520.00
-10400
300
-11400
La2001(1,1)

ODP Leg 154
Site 926

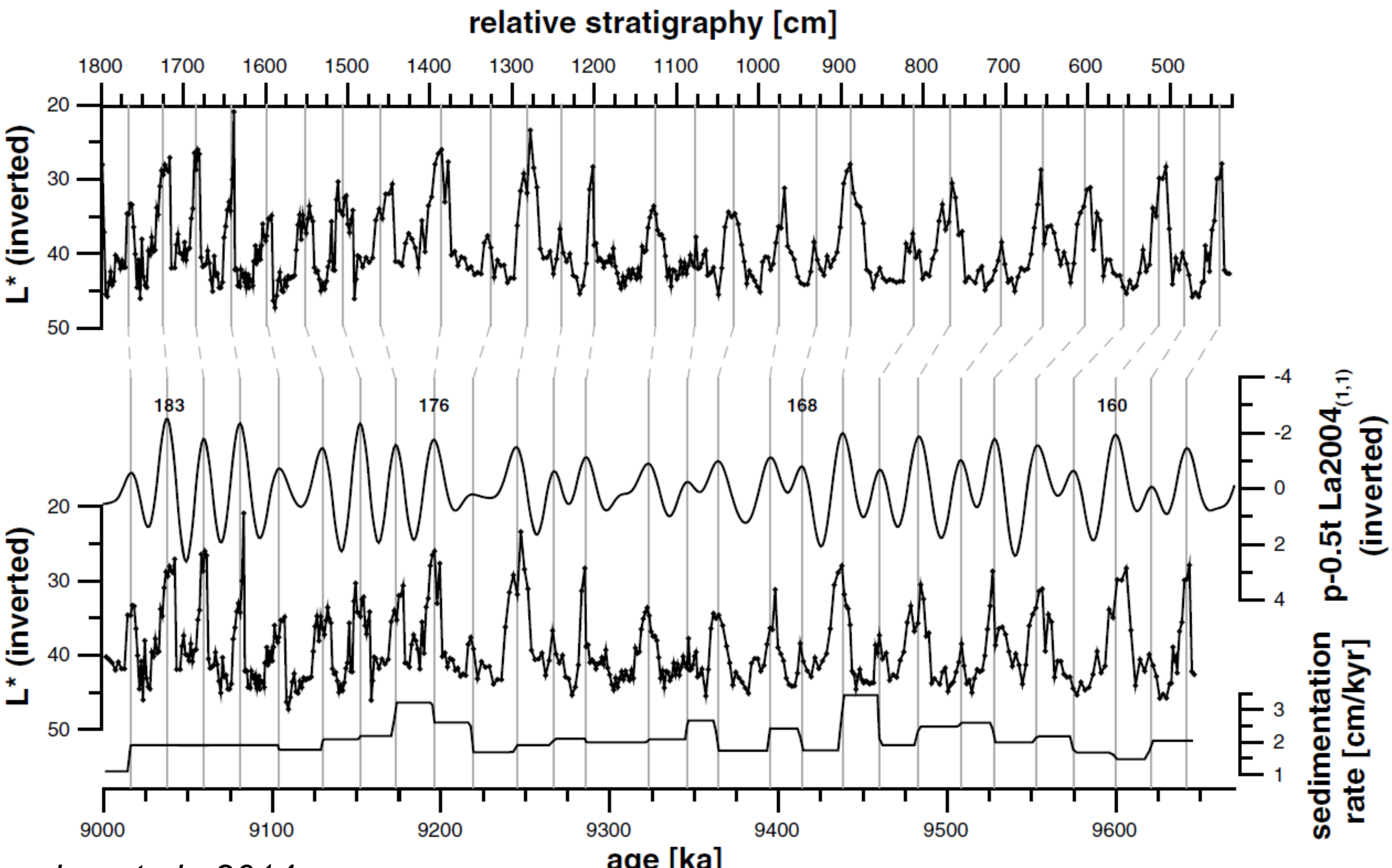
- Core A26-H




LEG
154
SITE
926
HOLE
A
CORE
26H
1
2
3
4
5
6
7
400
450
500
550
-11200
-11300
-11400
-11500
-11600
-11700
-11800
-11900
-12000
-12100
-12200
?
La2001(1,1)

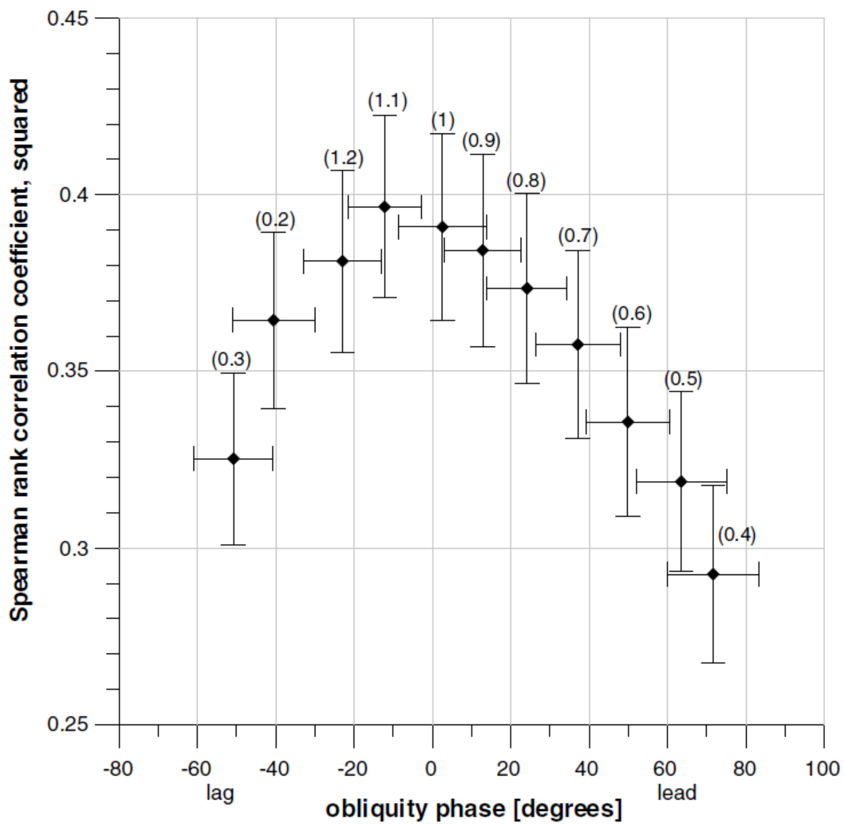

LEG
154
SITE
926
HOLE
A
CORE
26H
1 2 3 4 5 6 7
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150
400 440 480 520
-11200 -11300 -11400 -11500 -11600 -11700 -11800 -11900 -12000 -12100 -12200
La2001(1,1.2)

Monte dei Corvi

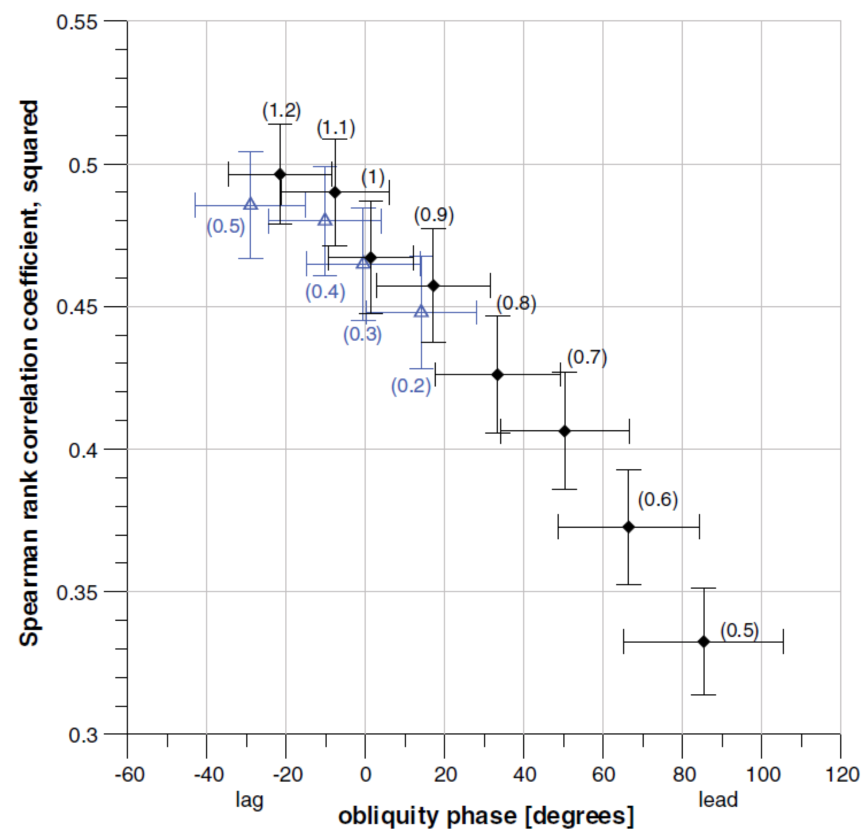


Zeeden et al., 2014

Correlation coefficient and obliquity phase



~9.5 Ma



~12.0 Ma

Zeeden et al., 2014

Conclusions

- Earth's orbital and inclination cycles have a marked effect on climate.
- Astronomical tuning underlies the standard GTS over the last 60-70 million years.
- The ATS will result in unit stratotypes for stages and Milankovitch cycles as chronozones.
- Climate models are very useful for understanding astronomical climate forcing.
- Paleoclimate data are needed to constrain the Td/dE values in the astronomical solution.

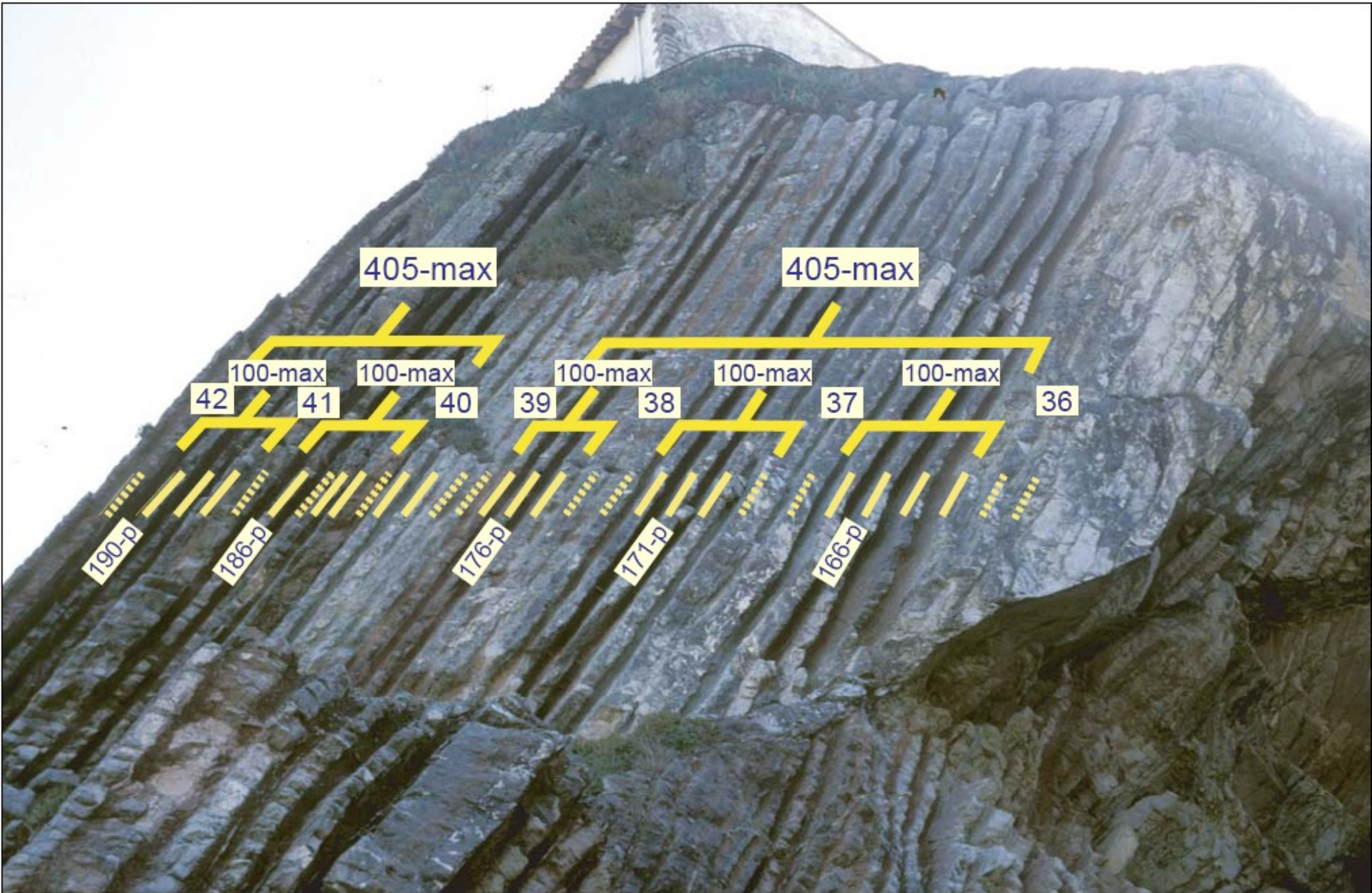
Jacques as geologist

Milankovitch on Mars

_home_www_videos_mro_mro20081204_mro20081204-1280.mov

Zumaia

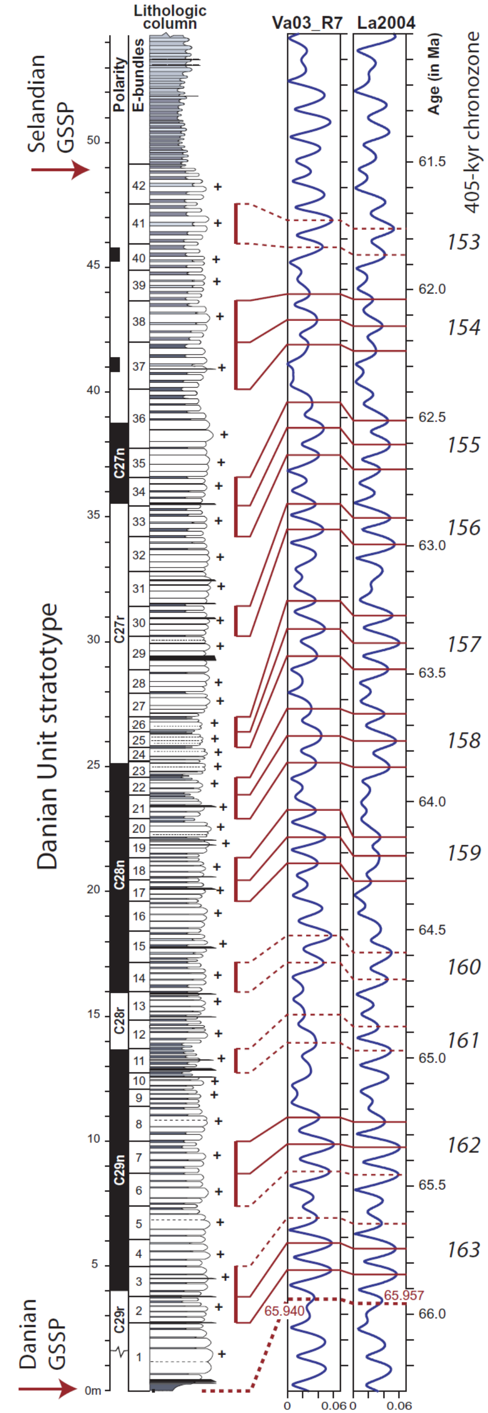
Zumaya



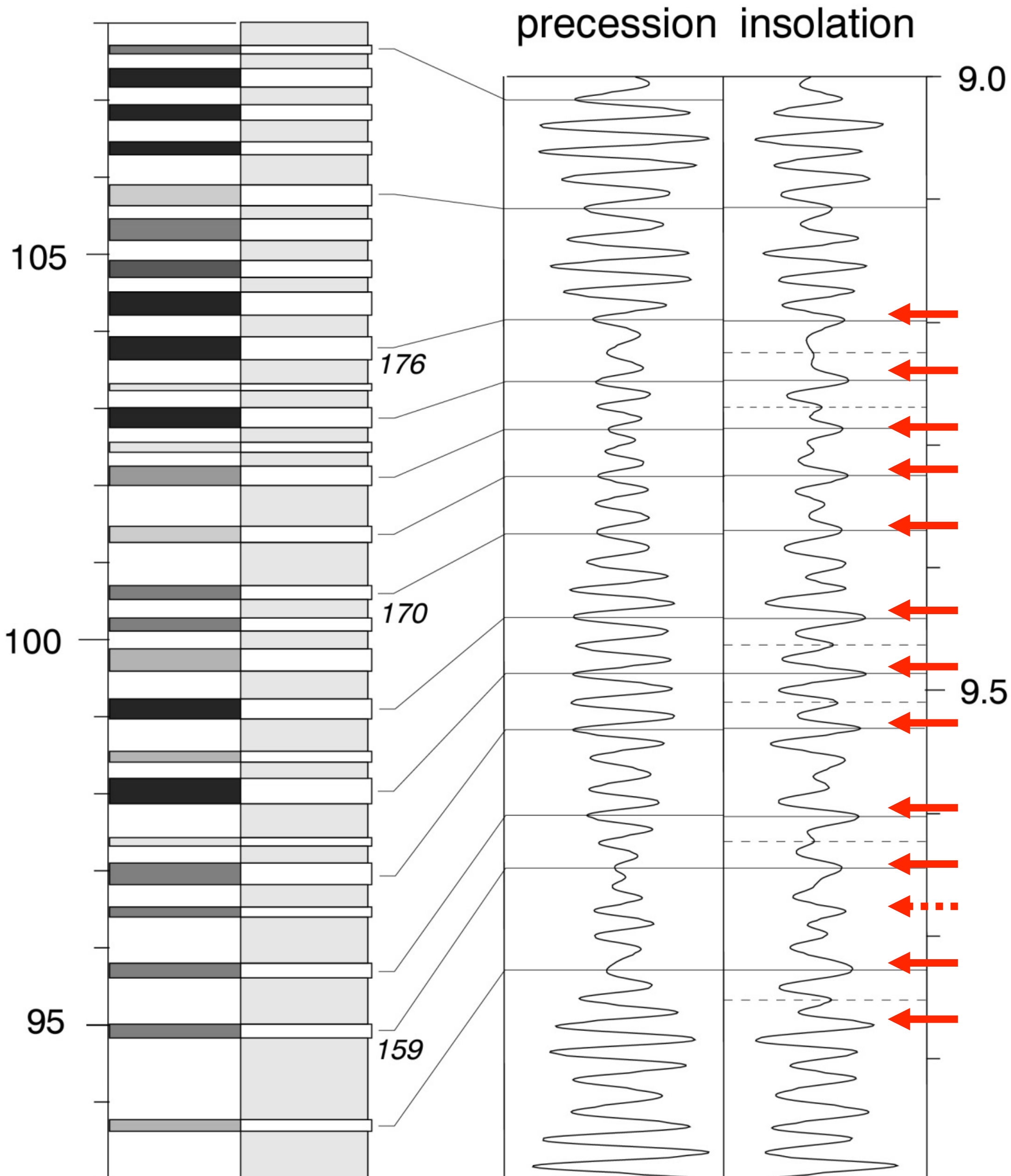
405-max
405-max
100-max
100-max
100-max
100-max
100-max
42
41
40
39
38
37
36
190-p
186-p
176-p
171-p
166-p

Danian
Unit Stratotype

- *Zumaia section*



Monte dei Corvi



P/O interference 9.5 Ma

La93$_{(1,1)}$

Laskar et al., 2004

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New astronomical results refine the Geological Time Scale (25 October 2004)

Released on October 25th, 2004

"A long-term numerical solution for the insolation quantities of the Earth", by Laskar et al.

(Published in *Astronomy & Astrophysics*.)

Original A&A article

A team led by Jacques Laskar from the Institut de Mécanique Céleste et de Calcul des Ephémérides (IMCCE) and the Paris Observatory has released new computational results for the long-term evolution of the orbital and rotational motion of the Earth. Following Milankovitch's theory of the paleoclimate that describes how major climatic changes on Earth are affected by astronomical events, these results have been employed to provide a new calibration of the sedimentary records over the 0 – 23.03 Myr geological period (the so-called Neogene period). Thus, Laskar et al.'s work has contributed to the definition of the new Geological Time Scale that has been adopted by the International Commission of Stratigraphy (ICS) and the International Union of Geological Sciences (IUGS). It is the first time that astronomical computations have been used to establish the ICS geological chronology over a full geological period.

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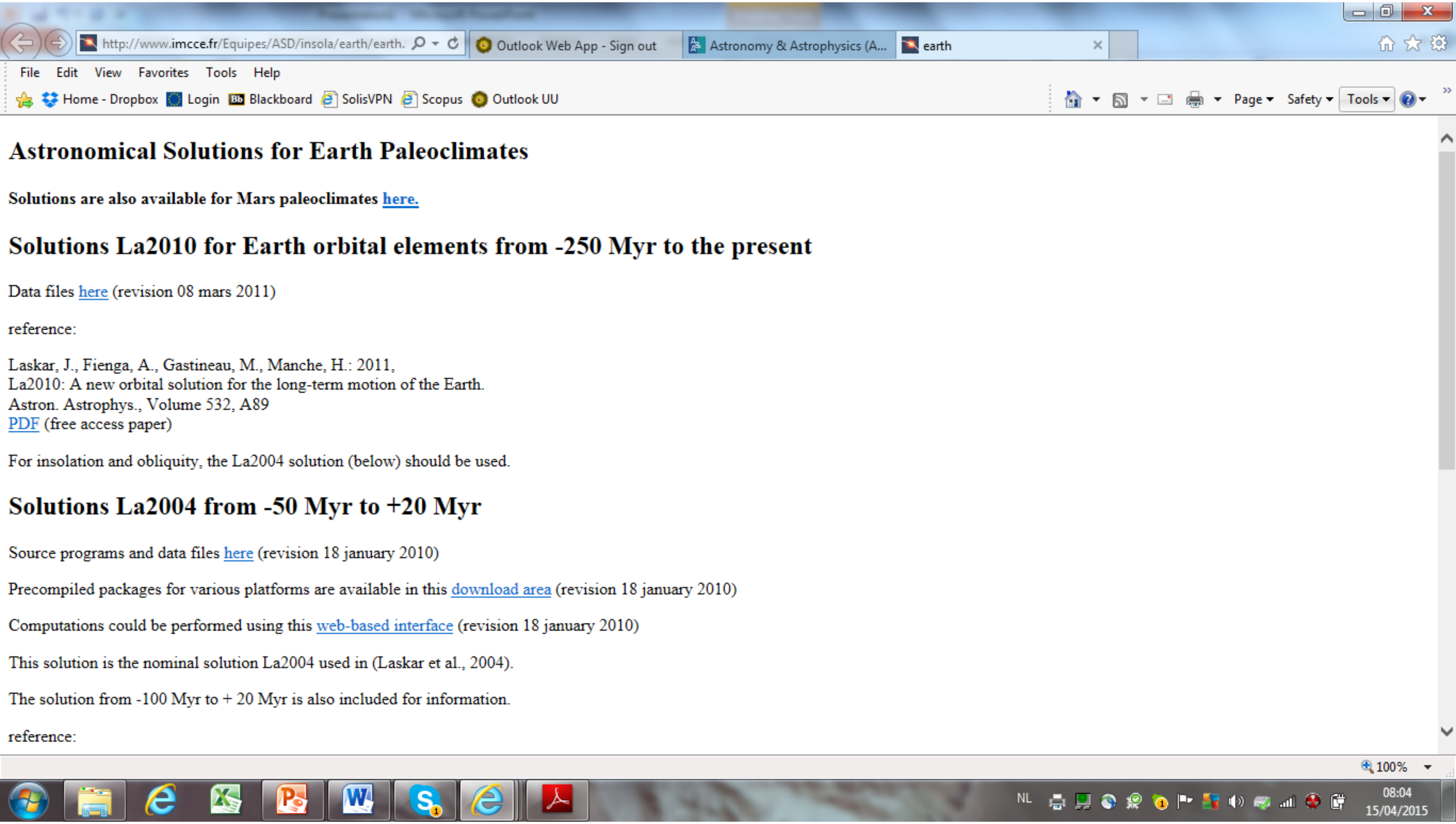
Laskar et al., 2004

- first time astronomical computations used to establish the chronology over a full geological period (Neogene, last 23 million years)
- makes it possible for paleoclimatologists to be *(much)* more precise in dating the geological events *and understand paleoclimate*
- The next step … is to provide an astronomical calibration of the Paleogene

Website of Jacques' group



Astronomical Solutions for Earth Paleoclimates

Solutions are also available for Mars paleoclimates here.

Solutions La2010 for Earth orbital elements from -250 Myr to the present

Data files here (revision 08 mars 2011)

reference:

Laskar, J., Fienga, A., Gastineau, M., Manche, H.: 2011,
La2010: A new orbital solution for the long-term motion of the Earth.
Astron. Astrophys., Volume 532, A89
PDF (free access paper)

For insolation and obliquity, the La2004 solution (below) should be used.

Solutions La2004 from -50 Myr to +20 Myr

Source programs and data files here (revision 18 january 2010)

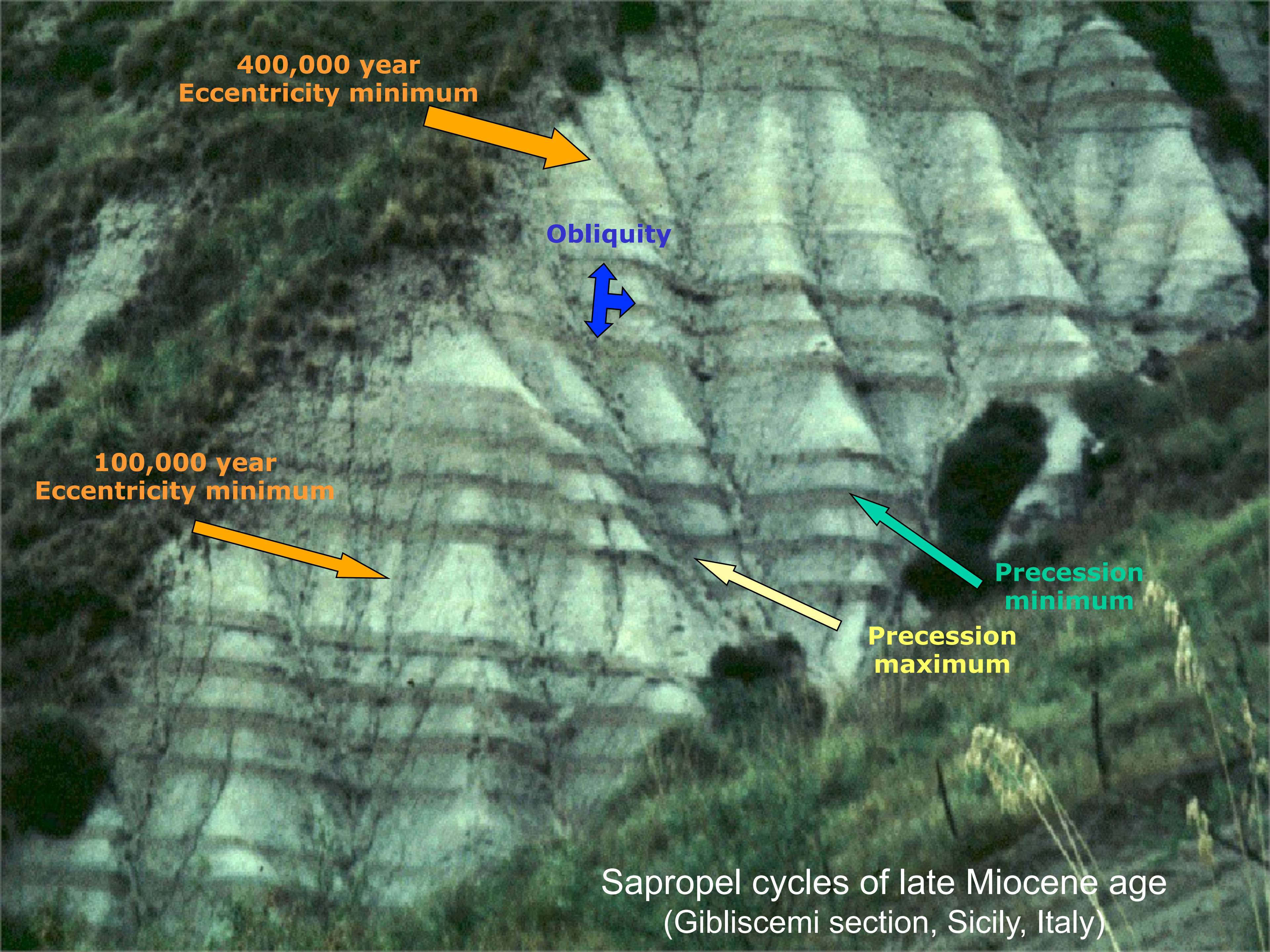
Precompiled packages for various platforms are available in this download area (revision 18 january 2010)

Computations could be performed using this web-based interface (revision 18 january 2010)

This solution is the nominal solution La2004 used in (Laskar et al., 2004).

The solution from -100 Myr to + 20 Myr is also included for information.

reference:



Sapropel cycles of late Miocene age
(Gibliscemi section, Sicily, Italy)