Stability of the East Antarctic Ice Sheet: Insights from IODP Site U1361

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and Expedition 318 Scientific Party

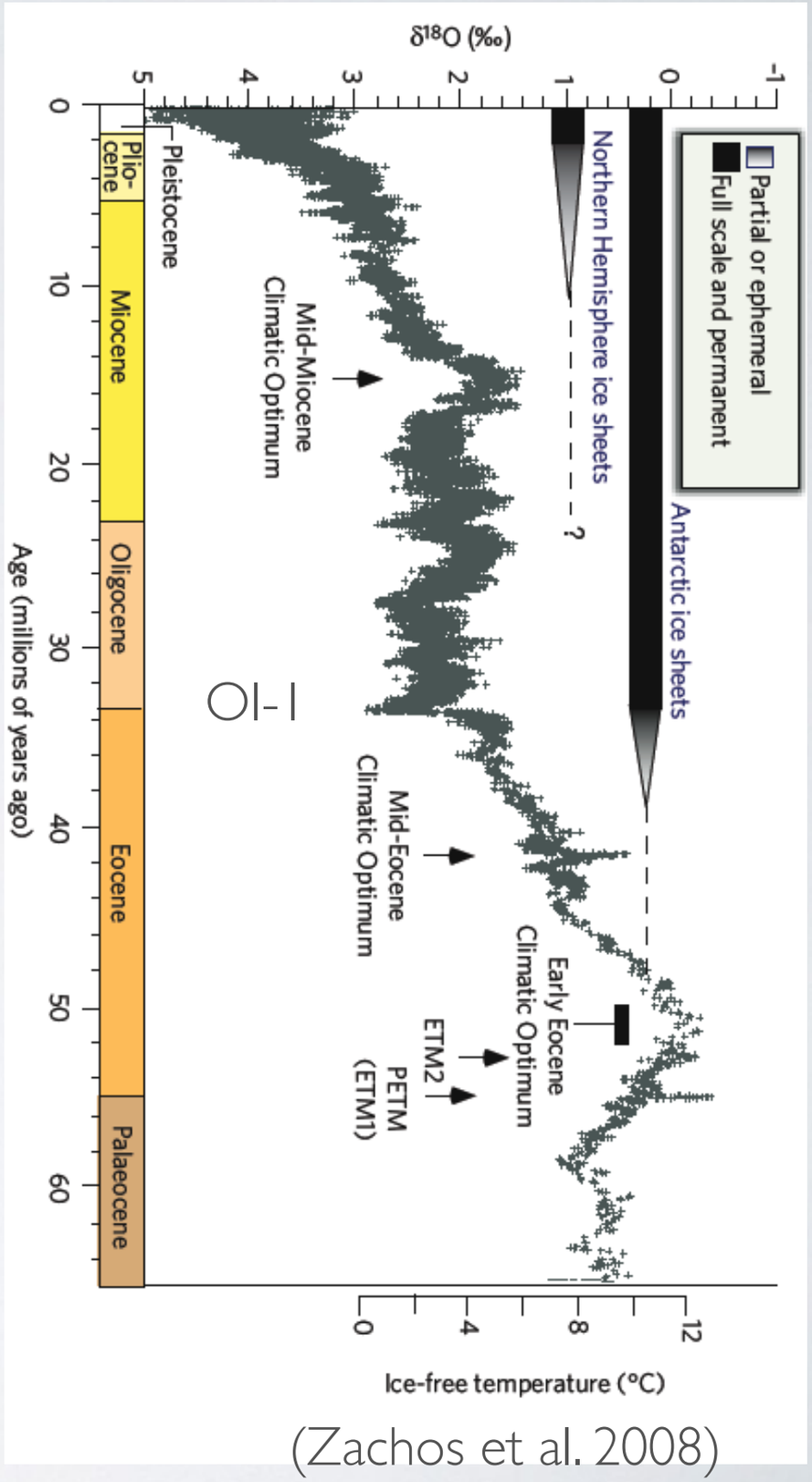
SCRIPPS INSTITUTION OF OCEANOGRAPHY UC San Diego

NSF National Science Foundation WHERE DISCOVERIES BEGIN

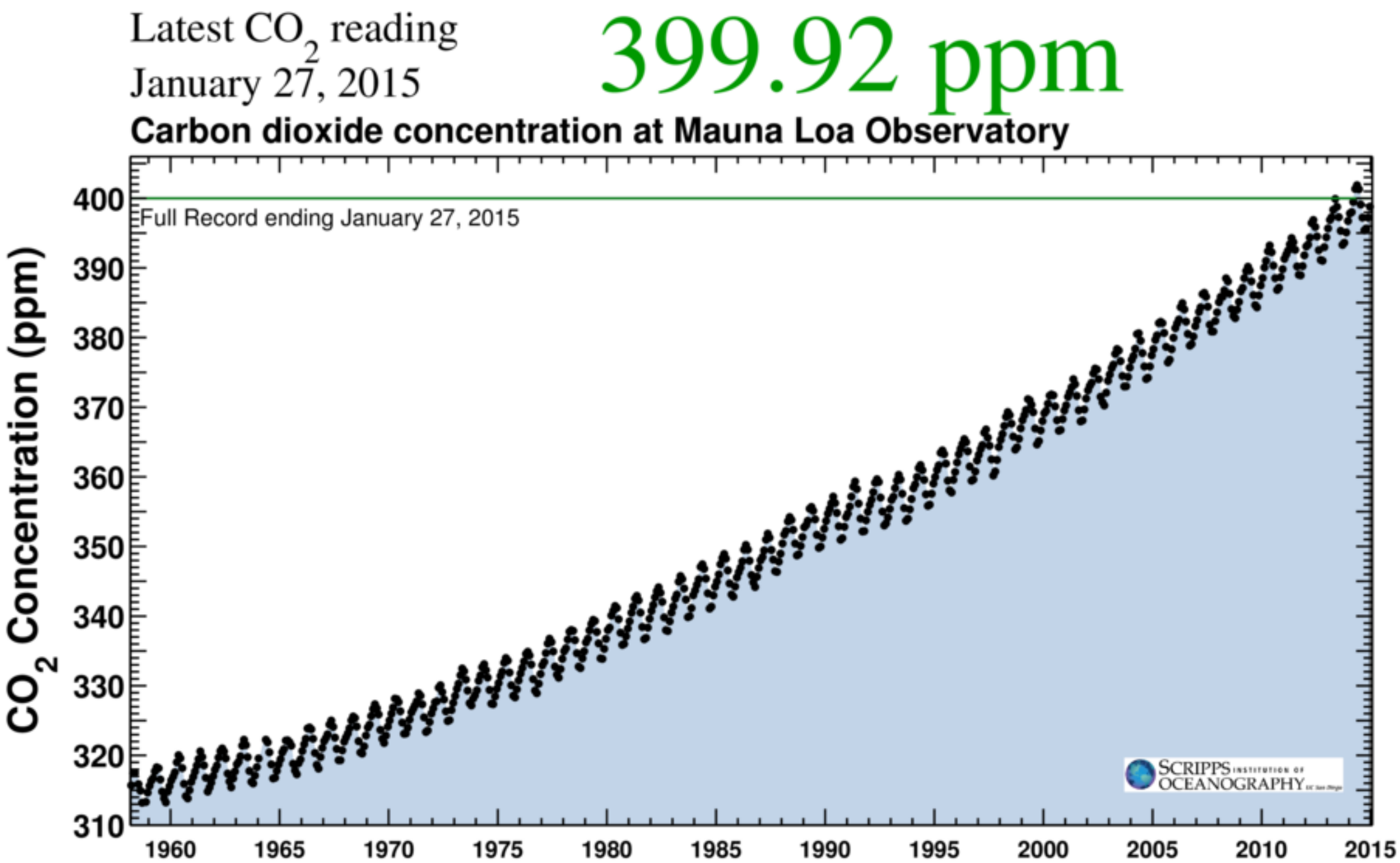
IODP International Ocean Discovery Program

PALEOMAGNETIC OBJECTIVES OF EXP 318

- Help date regional unconformities
- Help determine the ages of climate record from chemo, litho, bio, etc. stratigraphies
- Provide better age calibration for biostratigraphy from high southerly latitudes
- Provide insights into stability of East Antarctic Ice Sheet
- Provide a glimpse at sub-surface geology



(Zachos et al. 2008)



Scary picture from Keeling lab at Scripps

http://en.wikipedia.org/wiki/Keeling_Curve

As atmospheric CO_2 rises, climate models predict

- Increasing temperatures
- Increasing storm severity
- Increasing sea-level

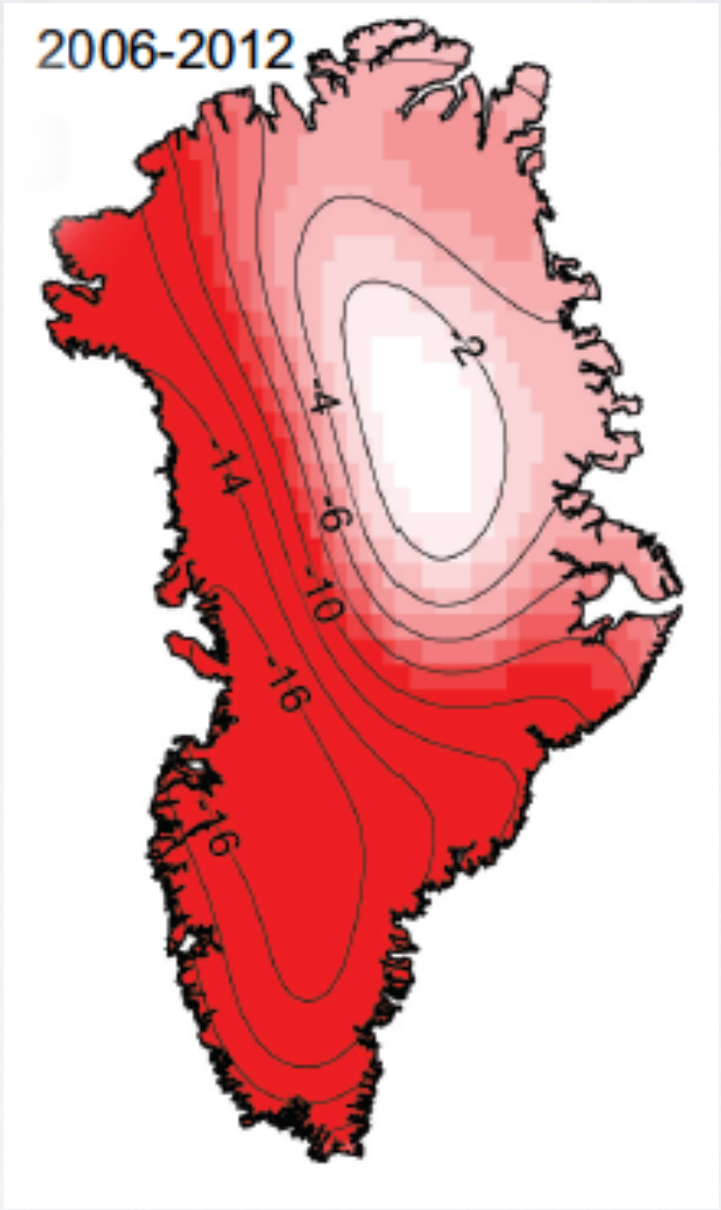
What drives sea-level rise?

- global temperature
- Melting of ice stored on the continents
  - Greenland Icesheet => 7 m rise
  - Western Antarctic Ice Sheet => 5 m rise
  - Eastern Antarctic Ice Sheet => 52 m!

(Lythe et al., 2001; Fretwell et al., 2013)

GREENLAND IS ALREADY GOING - FAST

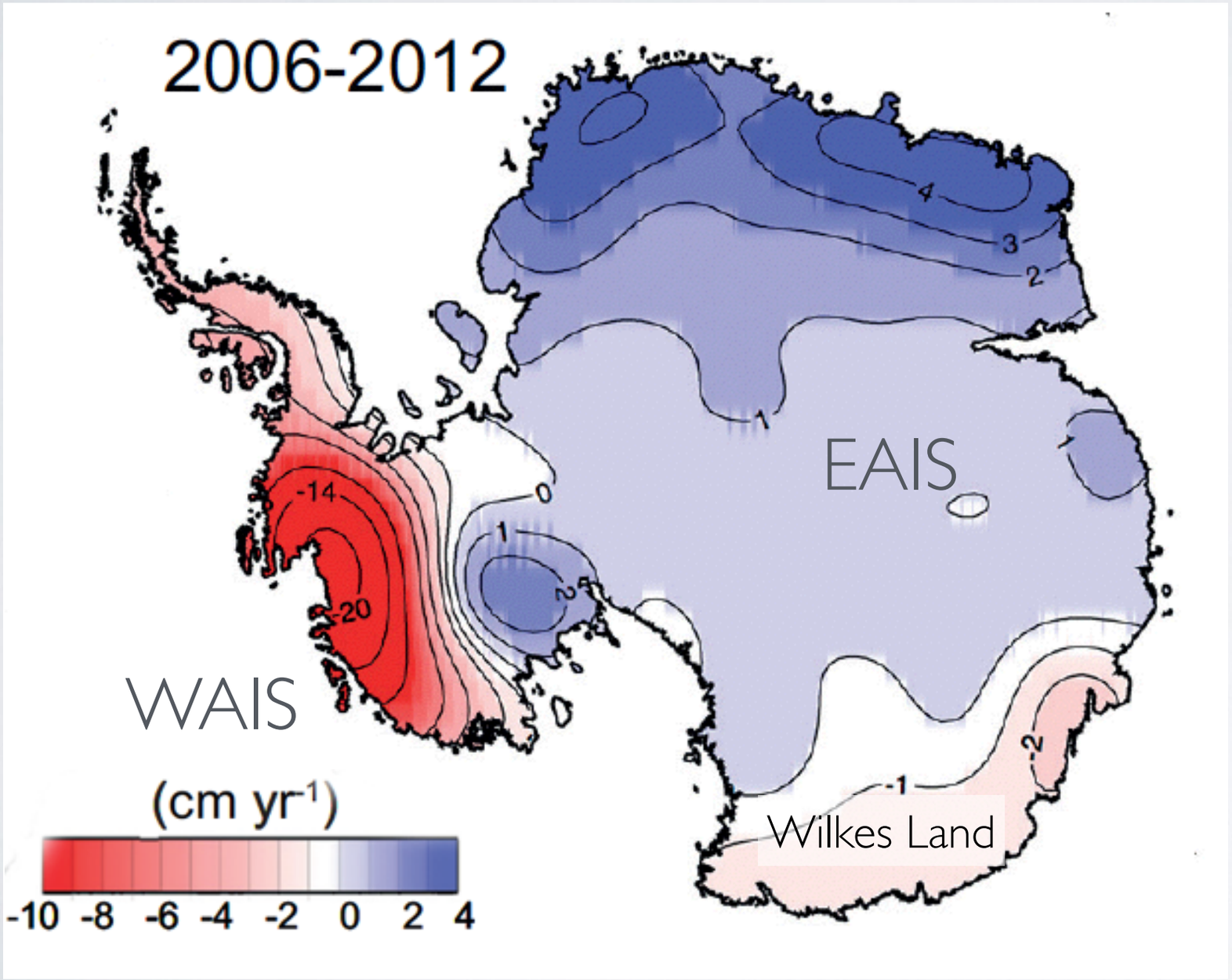
Change in ice surface elevation in cm/yr from GRACE satellite data



Vaughan et al., 2013

PICTURE IN ANTARCTICA

Change in ice surface elevation in cm/yr from GRACE satellite data



- WAIS melting fast
- Models* predict that EAIS will grow
- Data show parts are melting, especially Wilkes Land

Vaughan et al., 2013

*Huybrecht & de Wolde, 1999; Alley et al., 2006

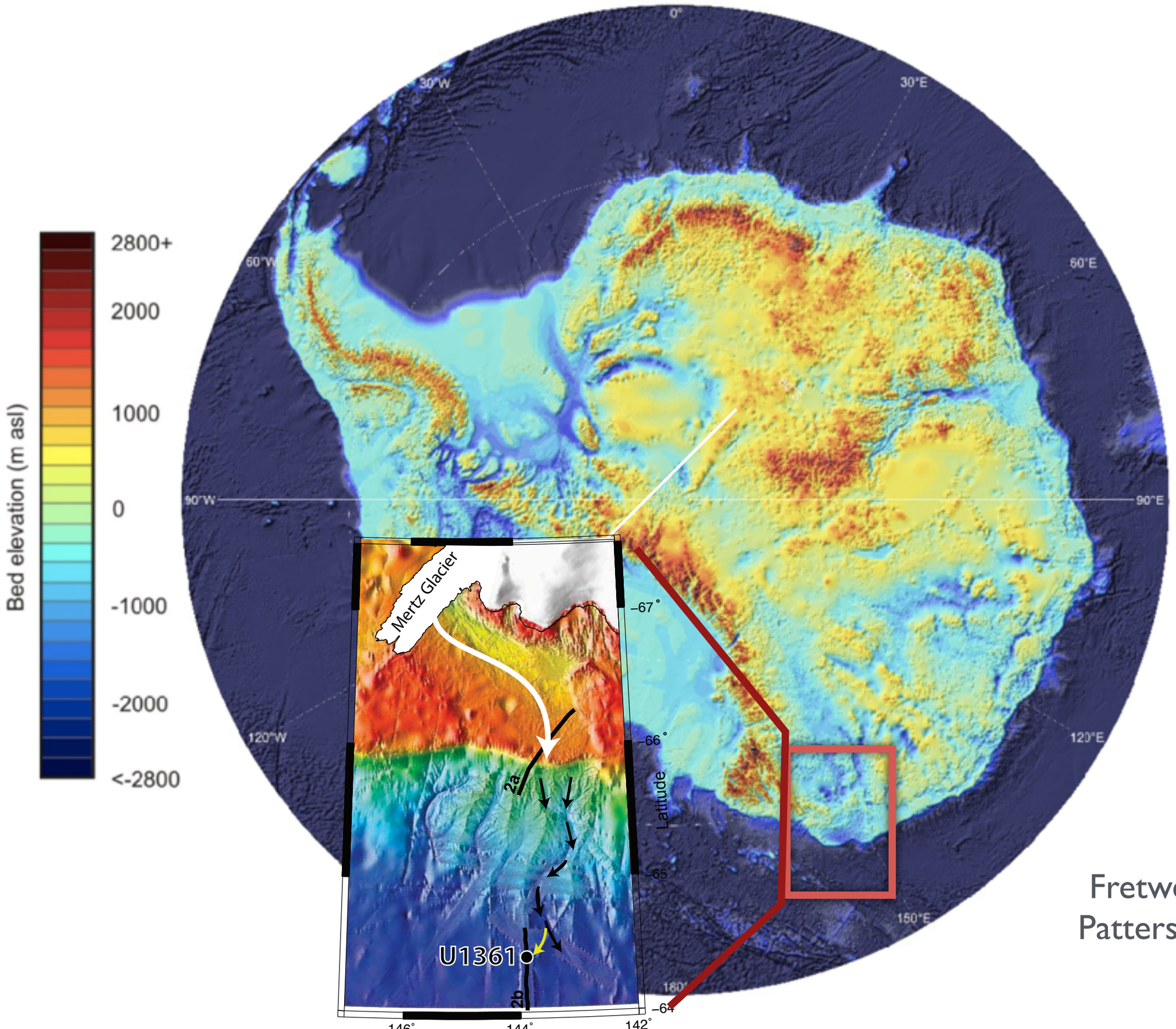
So what is the EAIS gonna do?

- Need to look back to time with elevated atmospheric CO_2
- But not too far back, with changes in plate configurations
- Need to look at the Pliocene

WHAT DID SEA-LEVEL DO IN THE PLIOCENE?

- Miller et al. (2012) summarized evidence and estimated that sea-level was 22 +/- 10 m higher than present.
- Greenland plus WAIS = 12 m, so EAIS "very likely" melted in the Pliocene
- But error bars are big…..
- Need a drill core off the coast of the EAIS, preferably near where it is melting today (Wilkes Land)

Bedmap 2 elevation map

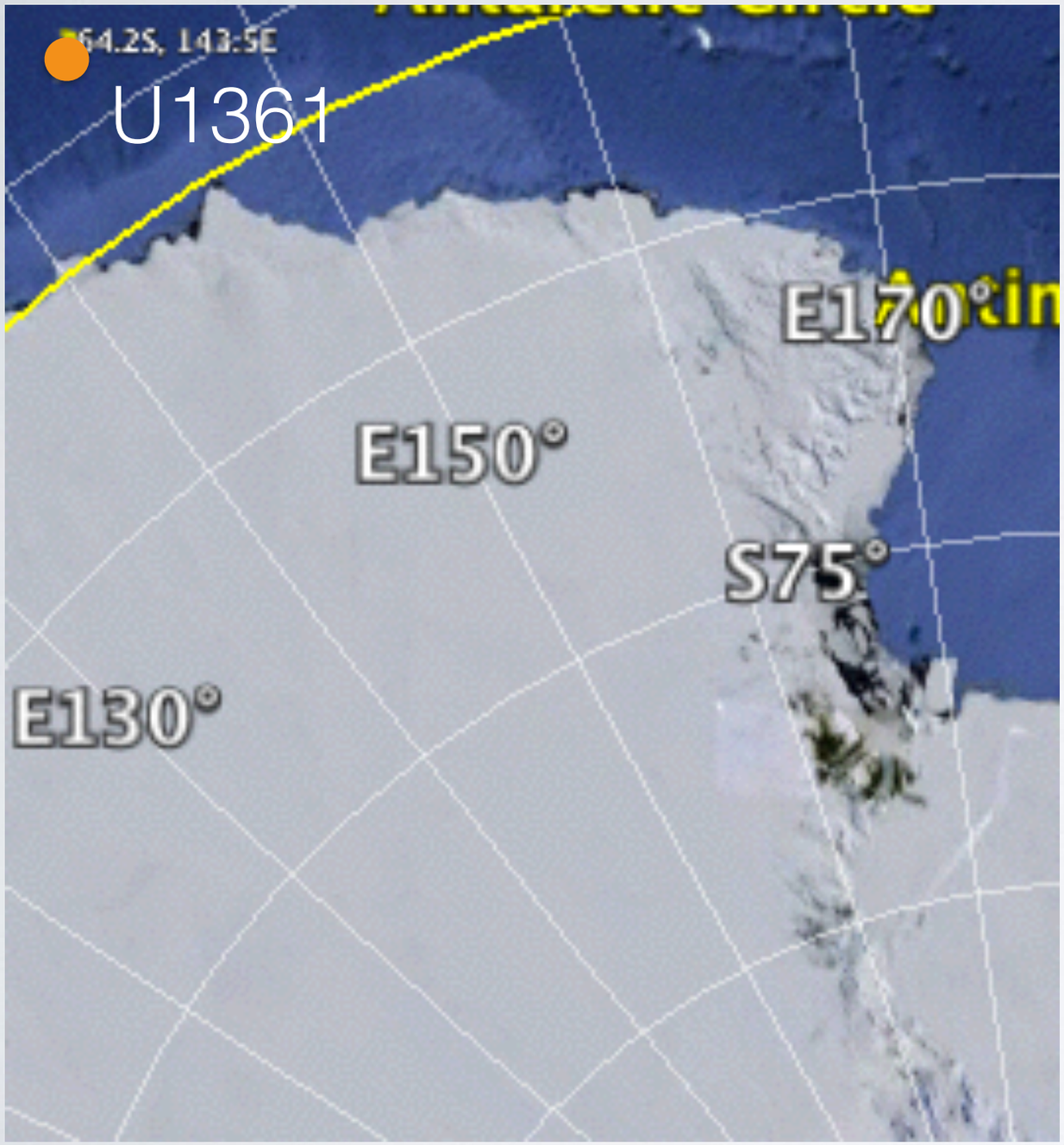


Fretwell et al., 2013
Patterson et al., 2014

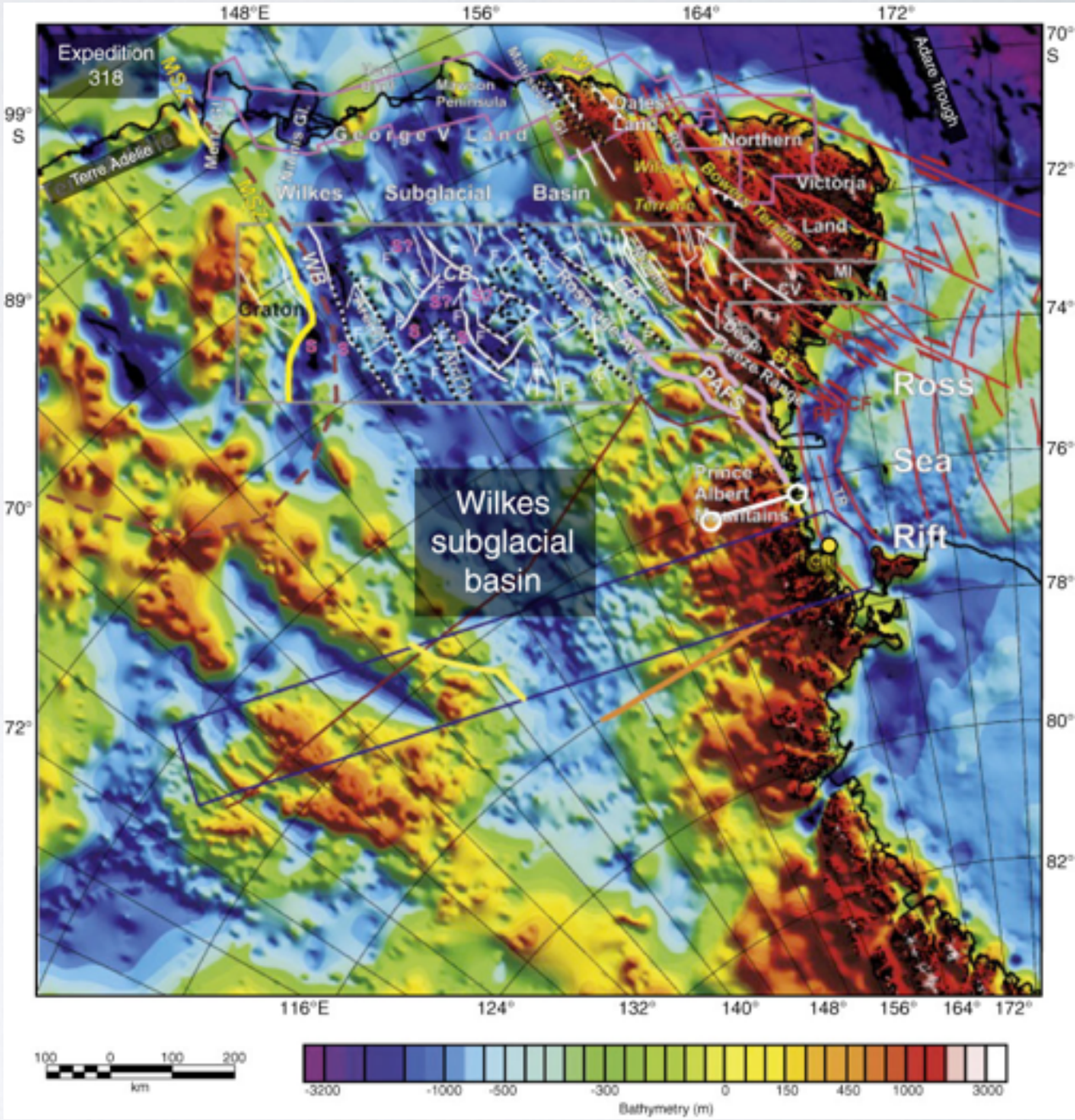
IODP SITE U1361 IDEALLY POSITIONED TO CATCH SEDIMENTS FROM WILKES LAND

SO WHAT CAN WE EXPECT TO CATCH?

The geology of the Wilkes land sub-basin is completely ice covered. Only indirect methods (gravity/magnetics) possible.

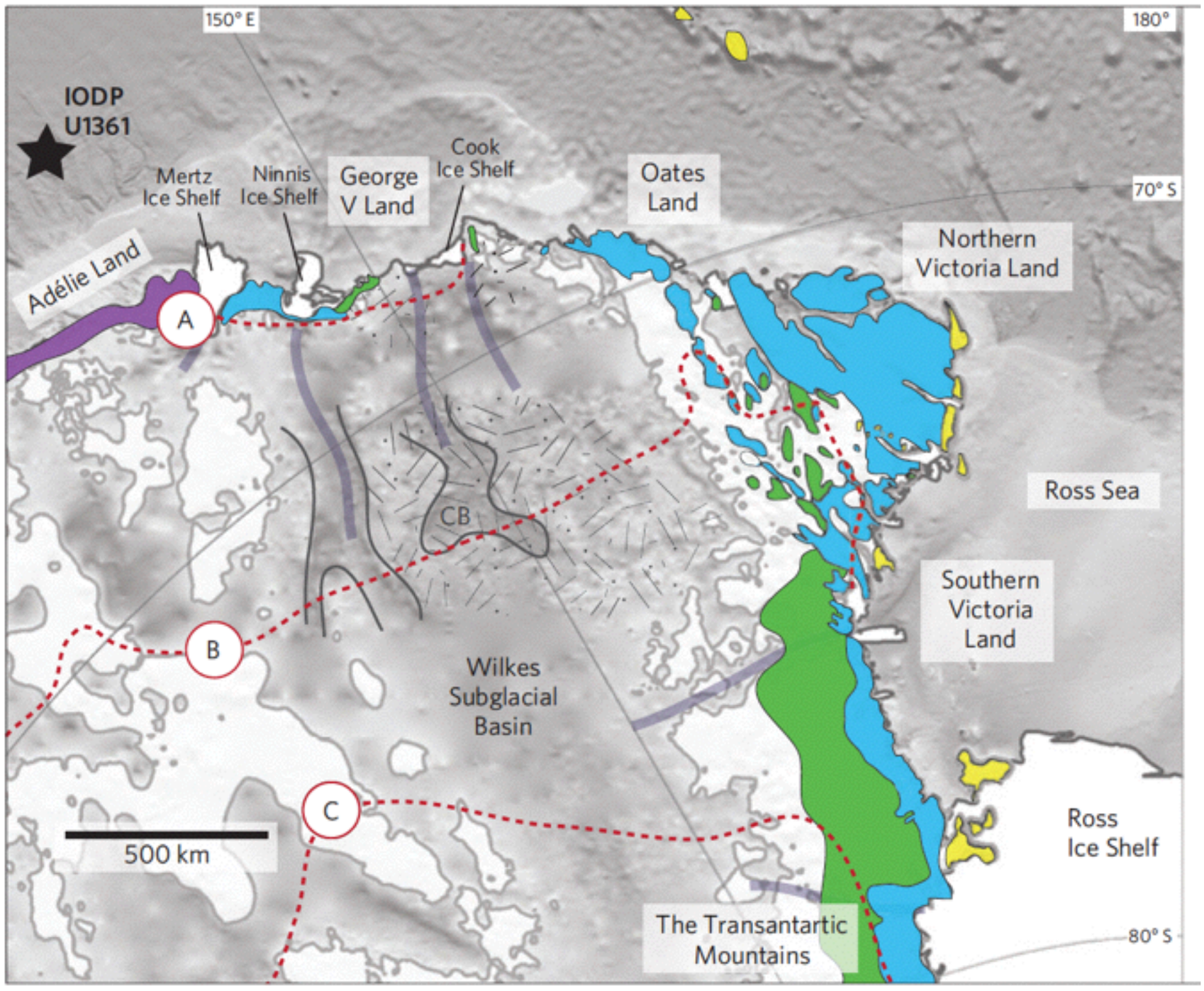


Google Earth



Ferraccioli et al., (2009); Escutia et al. (2011)

Best guess of what is under there



Archean/Proterozoic

Lower Paleozoic

Mesozoic (Ferrar)

Cenozoic volcanics

FLIP

Cook et al., 2013

Download the data:

http://earthref.org/MagIC/doi/10.1016/j.epsl.2014.12.034

earthref.org

rmation Consortium (MagIC) - Database Search Interface | Magnetics Information Consortium (MagIC) - Database Search Interface

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Magnetics Information Consortium (MagIC) - Database Search Interface

Online Resource for the International Paleomagnetic, Geomagnetic and Rock Magnetic Community

1 Filter | DOI = 10.1016/j.epsl.2014.12.034 | Find a Column

Contributions	Locations	Sites	Samples	Specimens	Synthetics	Measurements
1	1	2,454	2,454	2,454	0	4,092

Search | Create | Save As | Help

Summaries	Paleomagnetics	Rock Magnetics	Plots	Images
1	0	0	0	0

Formatted Mode

	Contribution	Actions	Records	Map	Classification	Data	Ages	Directions	Method Codes	Reference
1	**Tauxe et al. (2015)** by Lisa Tauxe on 28 Jan 2015 (ver. 1) http://earthref.org/MAGIC/10427/	Update	1 Location 2,454 Sites 2,454 Samples 2,454 Specimens 4,092 Measurements		**Class** Sedimentary **Type** Drill Site, Sediment Layer **Lithology** Silicate-Clay, Silty Clay		**0.42** to **12.61** Ma N = **619**	**2243** Declinations **1217** Inclinations	FS-C-DRILL-IODP SP-SS-C SO-V LT-T-Z LP-IRM-3D DE-VM LT-IRM ...	**Tauxe, L., Sugisaki, S., Jimenez-E de Fleirdt, T. and Iwai, M. (2015).** (and stability of the East Antarctic Ic at IODP Site U1361. *Earth and Plar 10.1016/j.epsl.2014.12.034.*

Install PmagPy

- Go to http://earthref.org/PmagPy/cookbook

Contents

PmagPy Cookbook

February 13, 2015
Dear Reader,

This documentation is updated from that in the book entitled Essentials of Paleomagnetism by Tauxe et al., (2010). This cookbook was designed as a companion website to the the book **Essentials of Paleomagnetism, 3rd Web Edition**. Chapter references to this companion book are, for example, "Essentials Chapter X".

There are many chefs who contributed to this work, in particular, the MagIC Database Team (Cathy Constable, Anthony Koppers, Rupert Minnett, Nick Jarboe, Ron Shaar, Nick Swanson-Hysell, and Lori Jonestrask). The PmagPy project is supported by grants from the National Science Foundation.

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February 13, 2015
http://magician.ucsd.edu/~ltauxe/

Read this section and follow the instructions

Chapter 1
Installing PmagPy

To skip all the details and just start using **QuickMagIC.py** to upload data into the **MagIC database**, follow these steps:

- If you are using Mac OSX, download and install the Enthought Canopy distribution of Python **https://www.enthought.com/products/canopy/**. Canopy Express (the free version) contains everything you need (except the mapping utilities). If you are at a degree-granting educational institution you can request an **academic license** that gives you access to additional features and bundled packages, including the basemap package. Launch Canopy to complete the installation process. You may need to use control click on the Canopy icon to open it for the first time - try this if you get a message that says "Canopy can't be opened because it is from an unidentified developer." Once you've opened Canopy successfully, select 'yes' to making Canopy your default Python environment. In the lower right hand corner of the Canopy launch page, you will find the Version number (currently 1.4.1.1975). Please include this in any correspondence with the PmagPy team. While you might find use for some of the features within the Canopy environment that opens as an application, PmagPy programs are best run at the command line in Terminal.
- Windows users should install this Enthought Distribution:

Unpacking the datafiles

- create a Project Directory
- Fire up QuickMagIC.py from the command line

QuickMagIC version: pmagpy-3.1.8

Choose MagIC project directory

change dir

/Users/ltauxe/Desktop/WilkesLand

Import MagIC formatted data to working directory

1. convert magnetometer files to MagIC format

2. (optional) calculate geographic/tilt-corrected directions

or

unpack downloaded txt file

3. fill Earth-Ref data using EarthRef Magic-Builder

Analysis and plots

Demag GUI

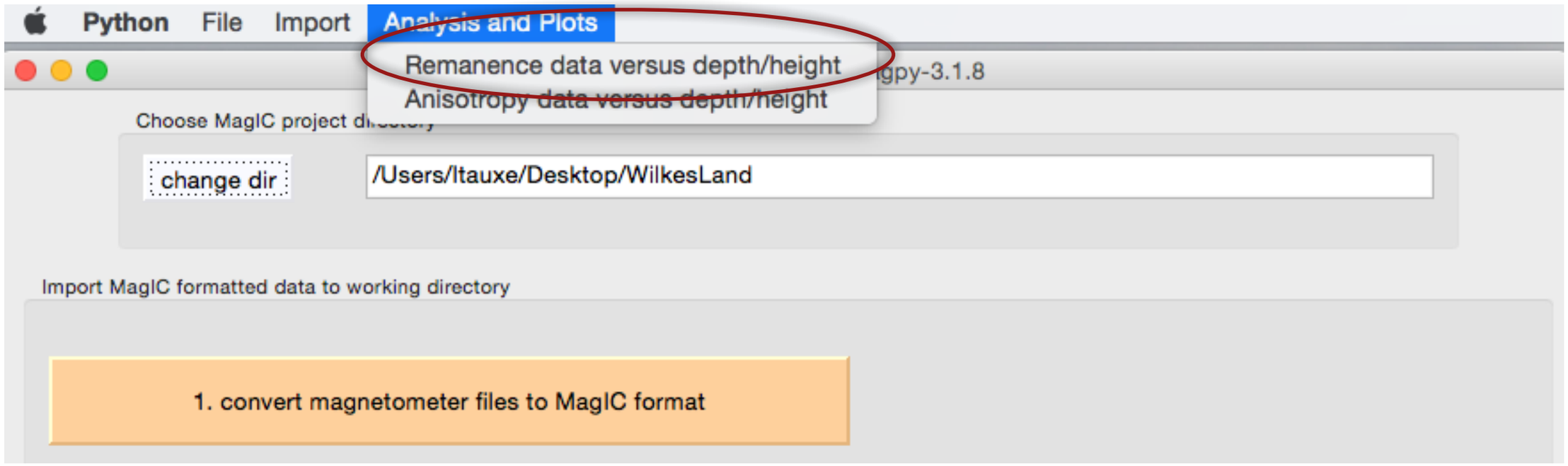
Thellier GUI

Upload to MagIC database

prepare upload txt file

Plot the inclination data

Under Analysis and Plots, choose: Remanence data vs depth/height/age



Remanence data versus depth/height

This program allows you to plot various measurement data versus sample depth.
You must provide either a magic_measurements file or a pmag_specimens file (or, you can use both).

Choose file (no spaces are allowed in path):

Don't use measurements file

add measurements file /Users/ltauxe/Desktop/WilkesLand/magic_measurements.txt

Plot display options for measurements data

choose color for plot points
- (•) blue
- ( ) green
- ( ) red
- ( ) cyan
- ( ) magenta
- ( ) yellow
- ( ) black
- ( ) white

choose shape for plot points
- (•) circle
- ( ) triangle_down
- ( ) triangle_up
- ( ) square
- ( ) star
- ( ) hexagon
- ( ) +
- ( ) x
- ( ) diamond

point size (default is 5): 5

[✓] Show lines connecting points

Choose file (no spaces are allowed in path):

Don't use pmag specimens file

add pmag_specimens file /Users/ltauxe/Desktop/WilkesLand/pmag_specimens.txt

Plot display options for specimens data

choose color for plot points
- ( ) blue
- ( ) green
- (•) red
- ( ) cyan
- ( ) magenta
- ( ) yellow
- ( ) black
- ( ) white

choose shape for plot points
- ( ) circle
- ( ) triangle_down
- (•) triangle_up
- ( ) square
- ( ) star
- ( ) hexagon
- ( ) +
- ( ) x
- ( ) diamond

point size (default is 5): 10

Choose file to provide sample data

(•) er_samples ( ) er_ages

Choose file (no spaces are allowed in path):

add er_samples file | /Users/ltauxe/Desktop/WilkesLand/er_samples.txt

Choose file (no spaces are allowed in path):

add IODP core summary csv file (optional) |

Choose what to plot:

- [ ] Plot declination
- [x] Plot inclination
- [ ] Plot magnetization
- [ ] Plot magnetization on log scale

Save plot in this format:

(•) svg
( ) eps
( ) pdf
( ) png

Experiment type

Lab Protocol: (•) AF ( ) T ( ) ARM ( ) IRM ( ) X

Step: 20

- [ ] Do not plot blanket treatment data

Depth scale

(•) Meters below sea floor (mbsf) ( ) Meters composite depth (mcd)

Specify depths to plot (optional)

minimum depth to plot (in meters) 40

maximum depth to plot (in meters) 160

Specify time scale to plot (optional)

[✓] Plot GPTS?

Time scale

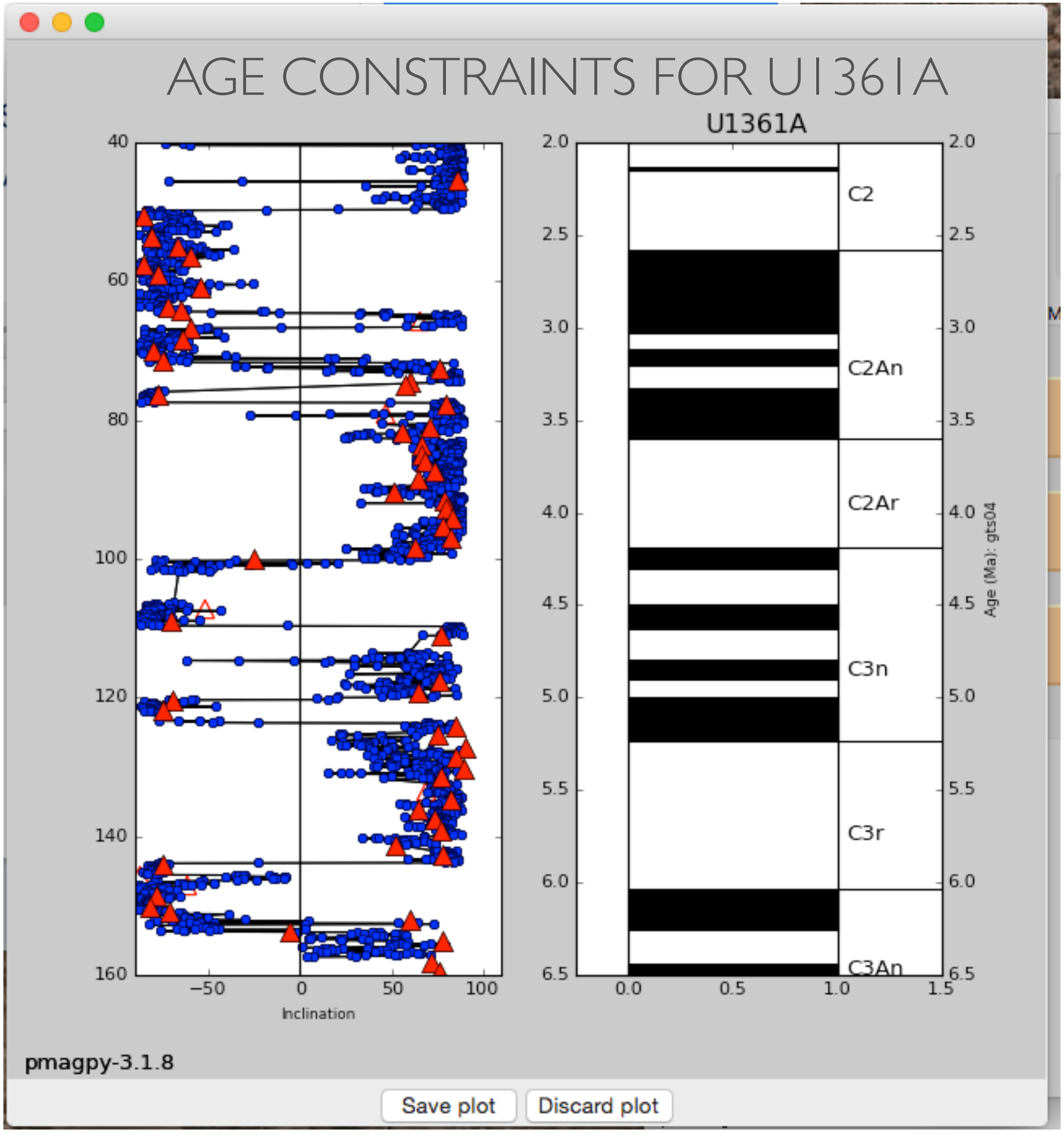
(•) gts04 ( ) ck95

Lower bound (in Ma) 2

Upper bound (in Ma) 6.5

OK Cancel Help

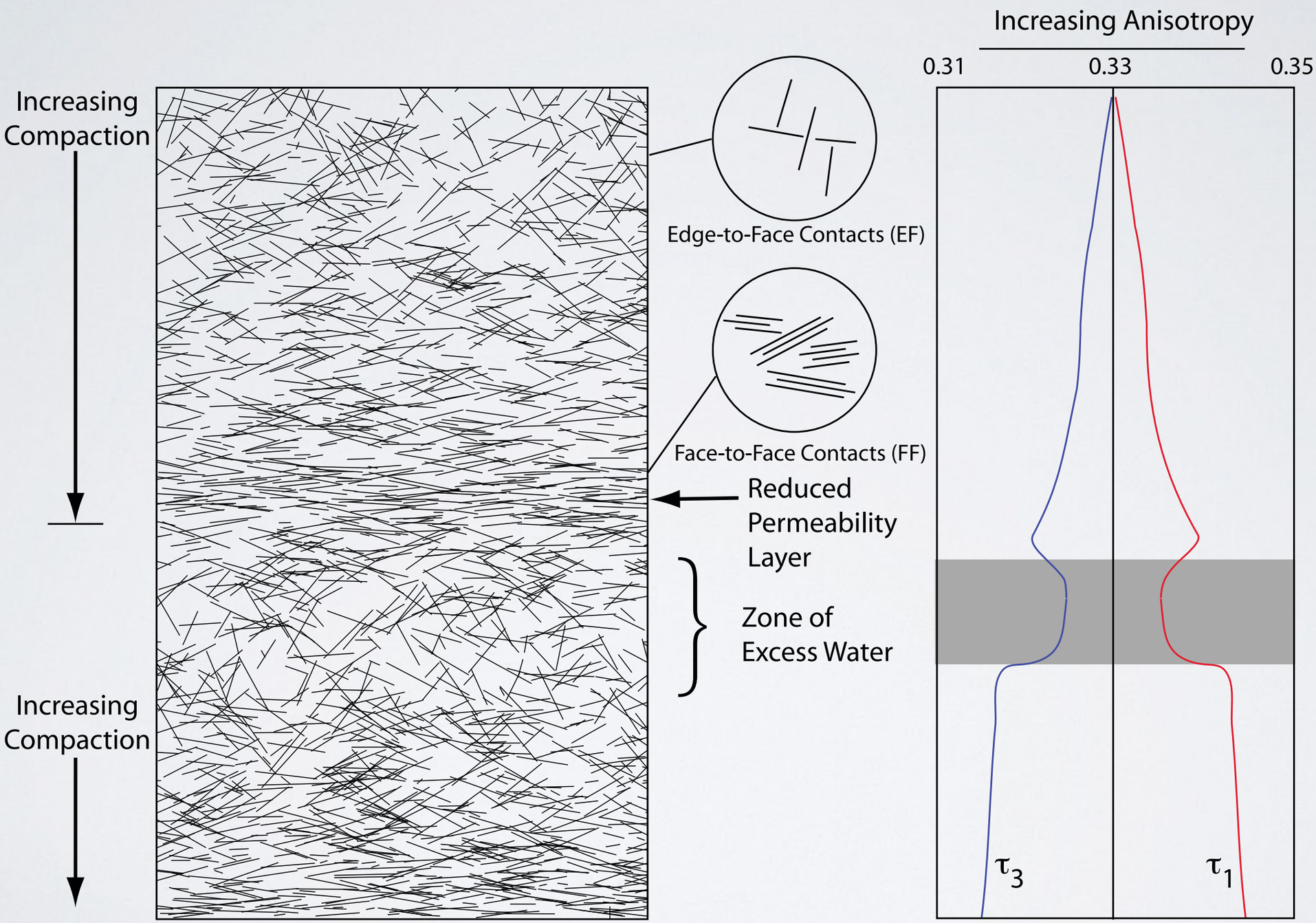
AGE CONSTRAINTS FOR U1361A



SO HOW CAN A POOR PALEOMAGNETIST HELP WITH THE STORY?

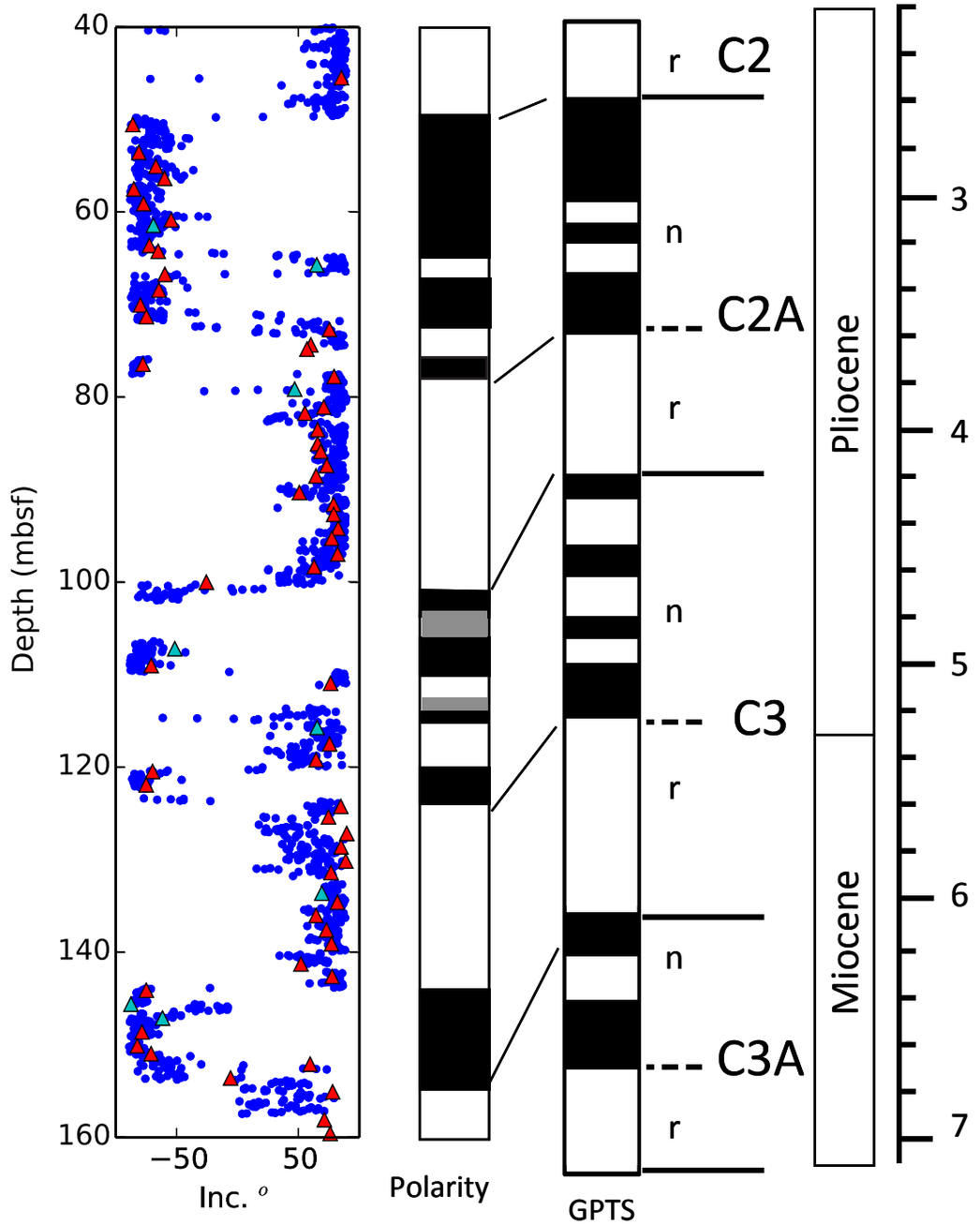
ROCK MAGNETISM

SEDIMENTARY FABRIC AND AMS

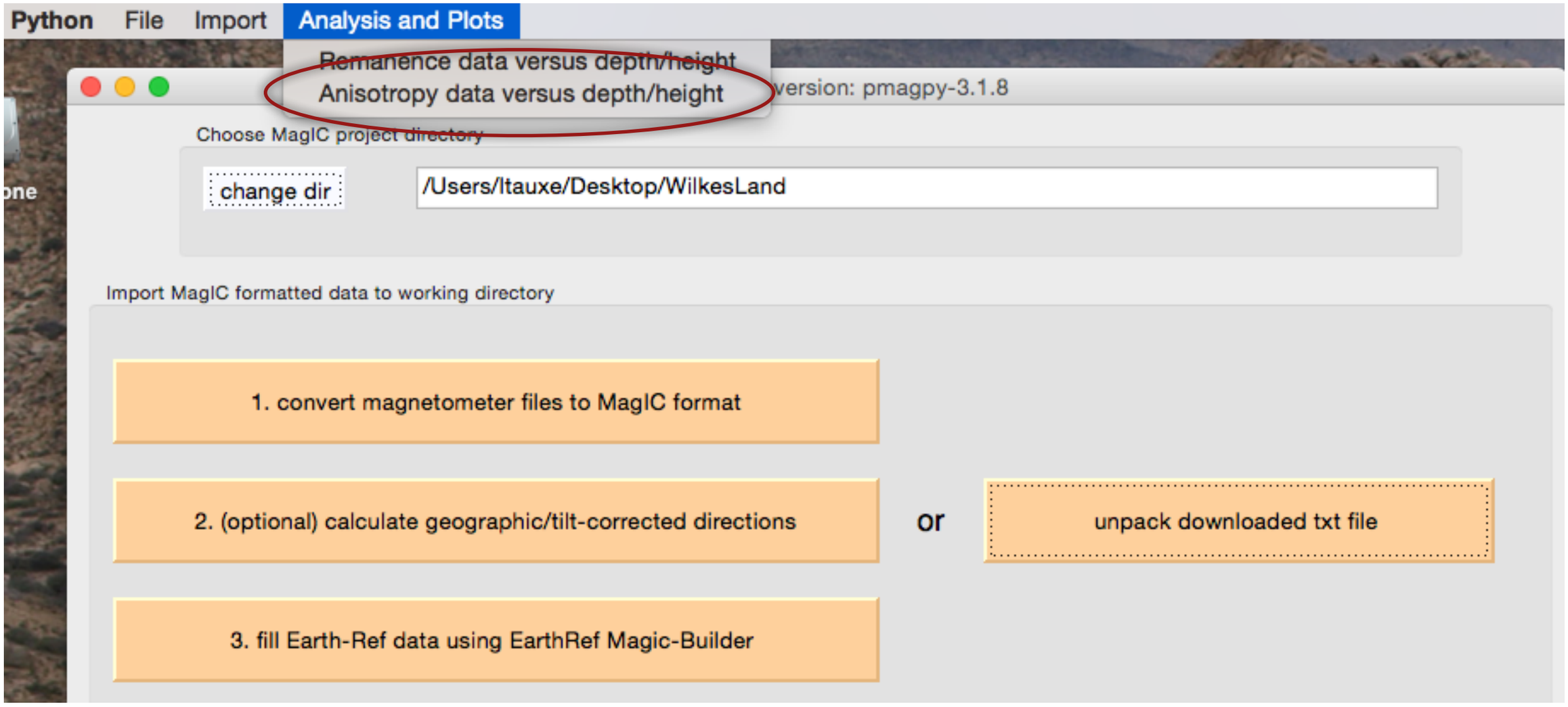


Schwehr et al., 2006

The plot so far….



Tauxe et al.,2015


Python
File
Import
Analysis and Plots
Remanence data versus depth/height
Anisotropy data versus depth/height
version: pmagpy-3.1.8
Choose MagIC project directory
change dir
/Users/ltauxe/Desktop/WilkesLand
Import MagIC formatted data to working directory
1. convert magnetometer files to MagIC format
2. (optional) calculate geographic/tilt-corrected directions
or
unpack downloaded txt file
3. fill Earth-Ref data using EarthRef Magic-Builder

Plot anisotropoy vs. depth

Anisotropy data can be plotted versus depth.
The program ANI_depthplot.py uses MagIC formatted data tables of the rmag_anisotropy.txt and er_samples.txt types.
rmag_anisotropy.txt stores the tensor elements and measurement meta-data while er_samples.txt stores the depths, location and other information.
Bulk susceptibility measurements can also be plotted if they are available in a magic_measurements.txt formatted file.

Choose file (no spaces are allowed in path):
remove rmag_anisotropy file
add rmag_anisotropy file /Users/ltauxe/Desktop/WilkesLand/rmag_anisotropy.txt

Choose file (no spaces are allowed in path):
remove magic_measurements file
add magic_measurements file /Users/ltauxe/Desktop/WilkesLand/magic_measurements.txt

Choose file to provide sample data
(•) er_samples ( ) er_ages

Choose file (no spaces are allowed in path):
add er_samples file /Users/ltauxe/Desktop/WilkesLand/er_samples.txt

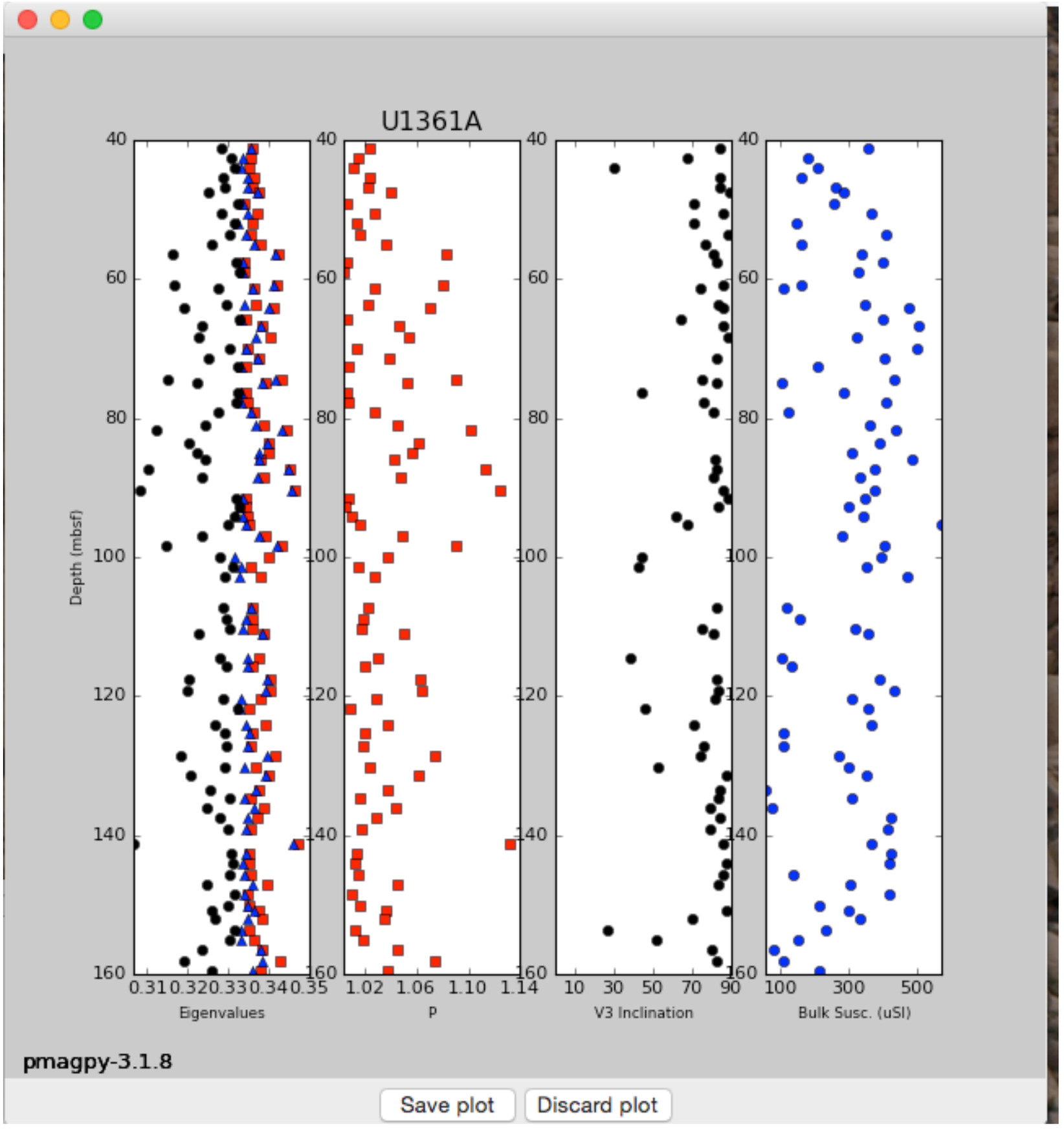
Save plot in this format:
(•) svg
( ) eps
( ) pdf
( ) png

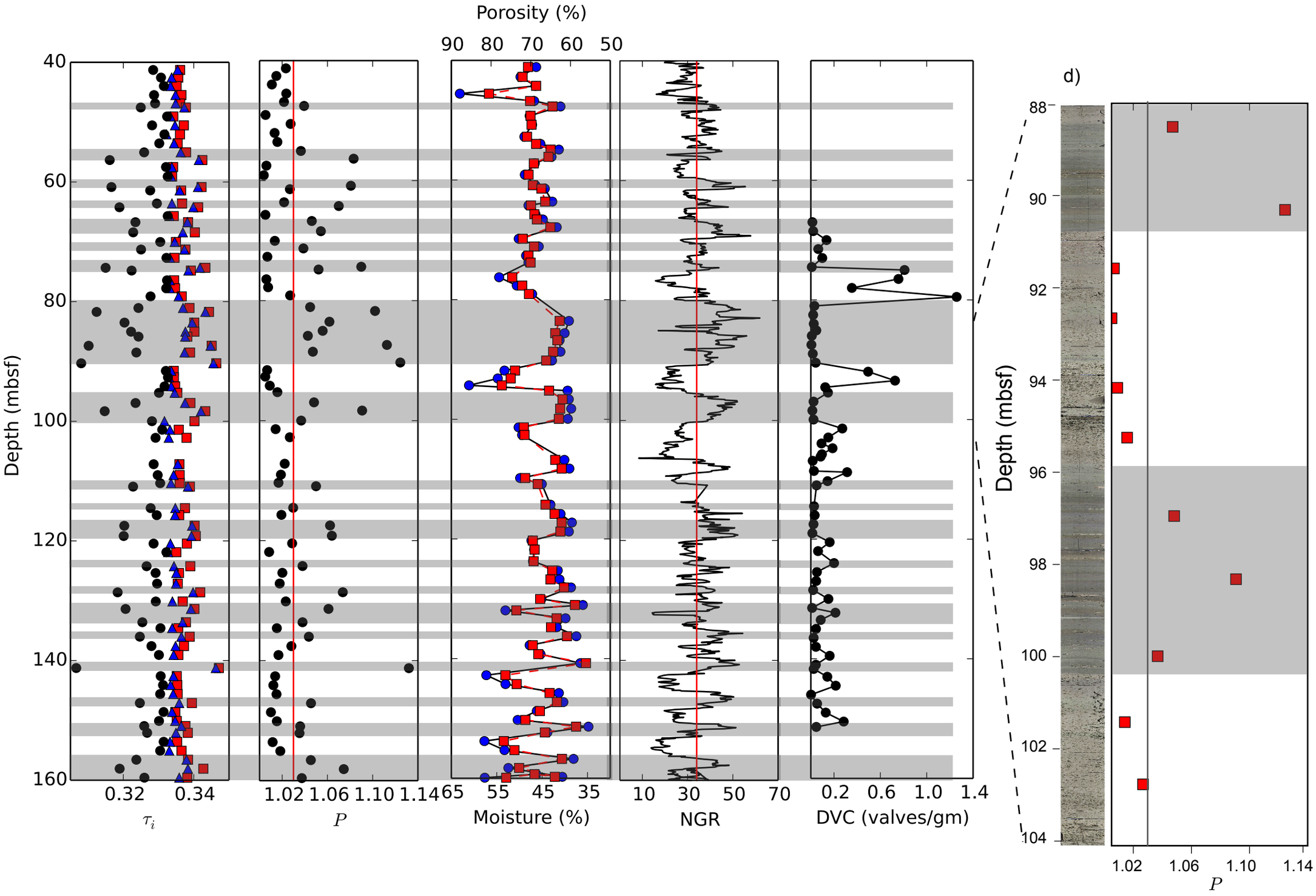
Depth scale
(•) Meters below sea floor (mbsf) ( ) Meters composite depth (mcd)

minimum depth to plot (in meters) 40

maximum depth to plot (in meters) 160

OK Cancel Help


U1361A
Depth (mbsf)
Eigenvalues
P
V3 Inclination
Bulk Susc. (uSI)
pmagpy-3.1.8
Save plot
Discard plot



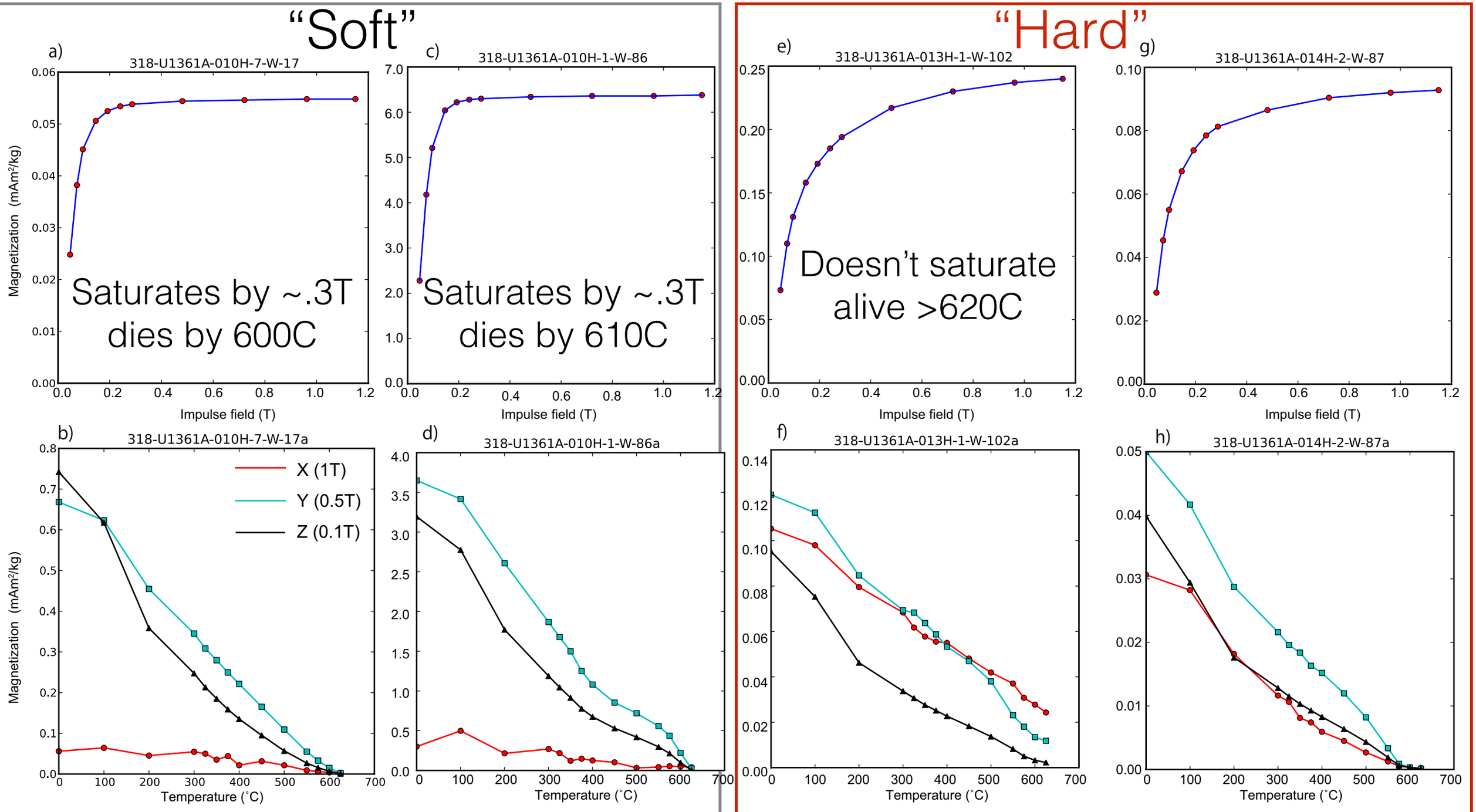
Tauxe et al.,2015

SUMMARY OF WHAT WE THINK WE KNOW SO FAR

- High anisotropy layers (shaded grey) have higher Natural Gamma Radiation (NGR), higher Al (clay), and lower porosity and moisture content.
- grey shaded stuff is “laminated greenish silty clay” - turbidites deposited on levee overbank
- white shaded stuff is “bioturbated greenish grey diatomaceous silty clay”
- “white stuff” is associated with higher productivity (from Ba/Al ratio - not shown), hence probably was warmer
- “grey stuff” is lower productivity, hence probably cooler
- LEAP: grey and white units are glacial/interglacial facies

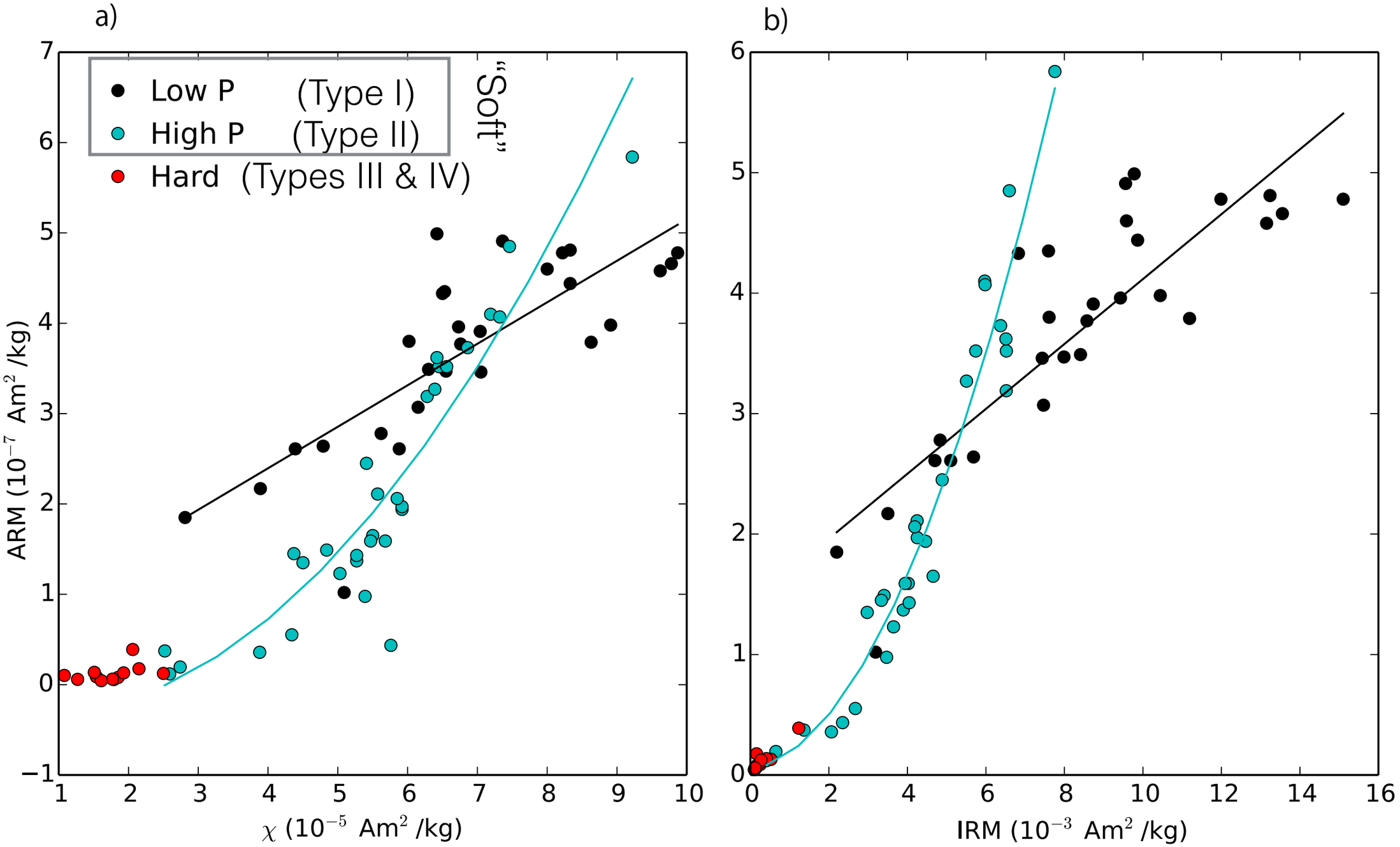
Back to Rock Mag 101

- Anisotropy of Magnetic Susceptibility
- Isothermal Remanent Magnetization



- Four types of behavior in IRM and 3d-IRM demagnetization experiments: Type I: magnetite; Type II: maghemite; Type III: hematite; Type IV: "hard" magnetite

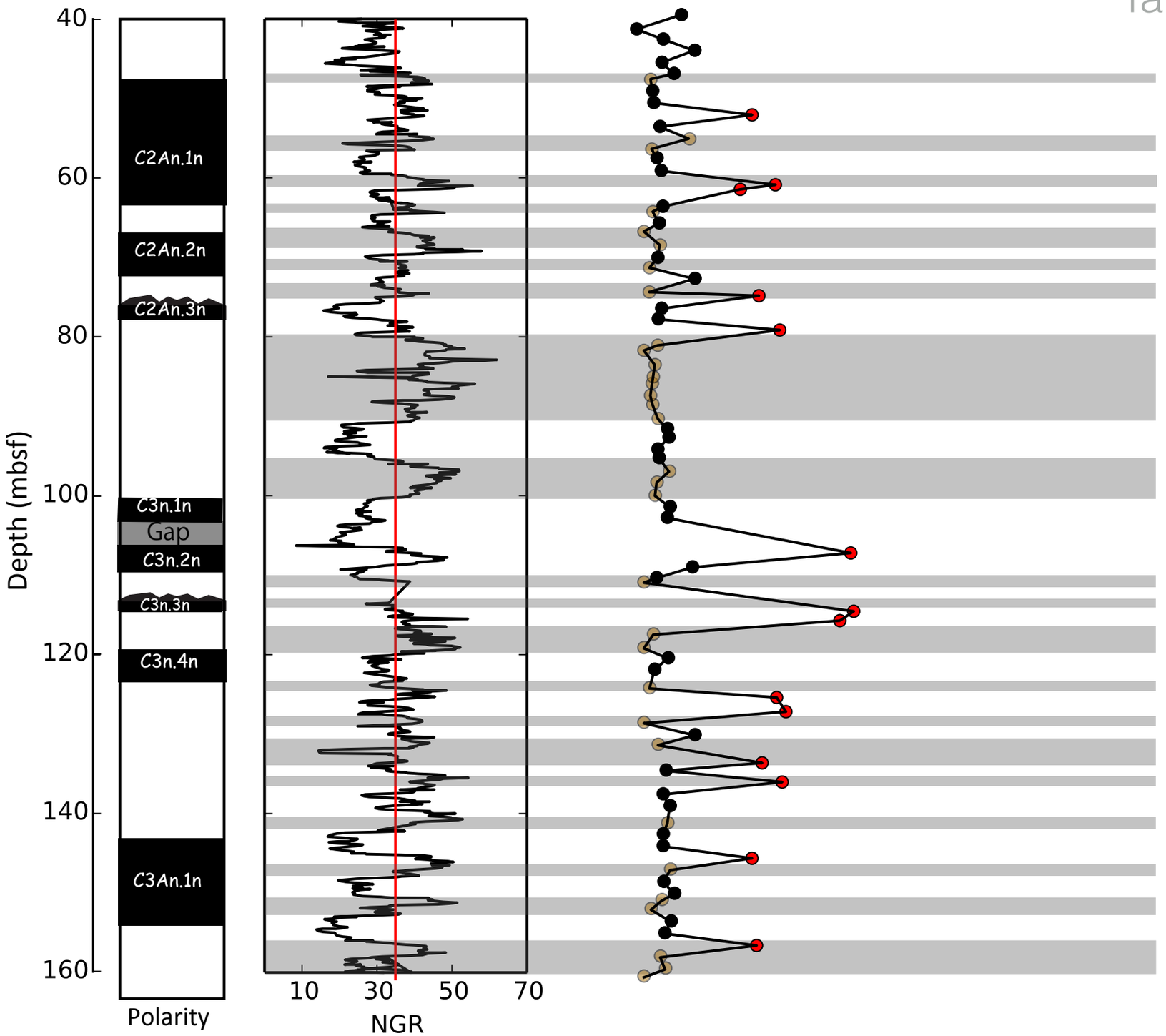
Tauxe et al.,2015



- Three rock magnetic groups
- Soft: Low P (white) = bioturbated= (magnetite)
- Soft: High P (grey) = laminated (maghemite)
- "Hard" Intermediate P (mostly hematite)

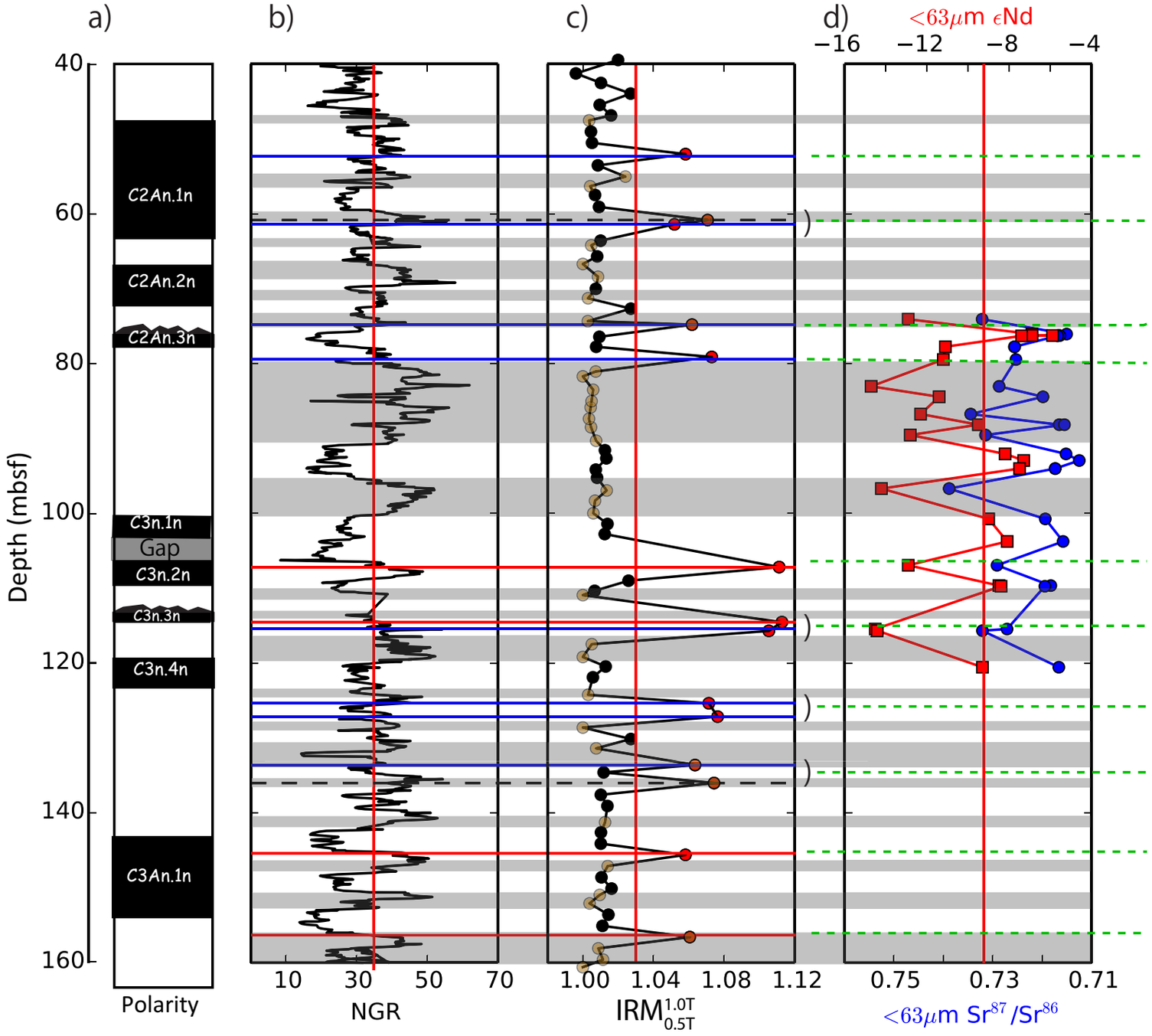
Tauxe et al.,2015

Tauxe et al.,2015



- Type I (black dots): all low anisotropy
- Type II (brown dots): all high anisotropy
- Types III&IV (red dots) : all at boundaries between the two

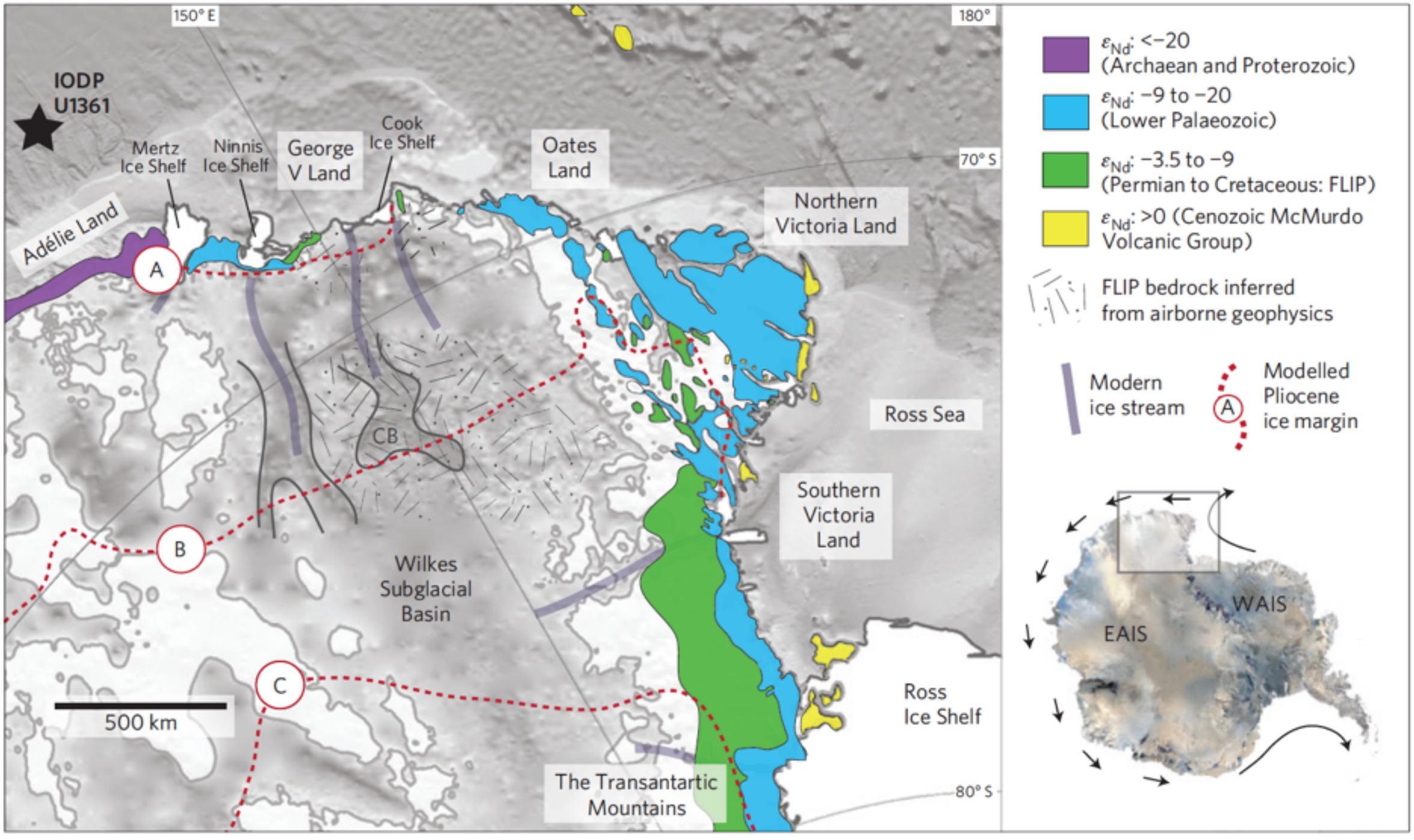
Tauxe et al.,2015



- Type I (black dots): all low anisotropy; Type II (brown dots): all high anisotropy; Types III&IV: all at boundaries between the two

- Sr and Nd isotopes (Cook et al., 2013) point to two distinct sources for low and high anisotropy layers

Cook et al., 2013



Blue: found in “laminated silty clay” units (cold); Type I

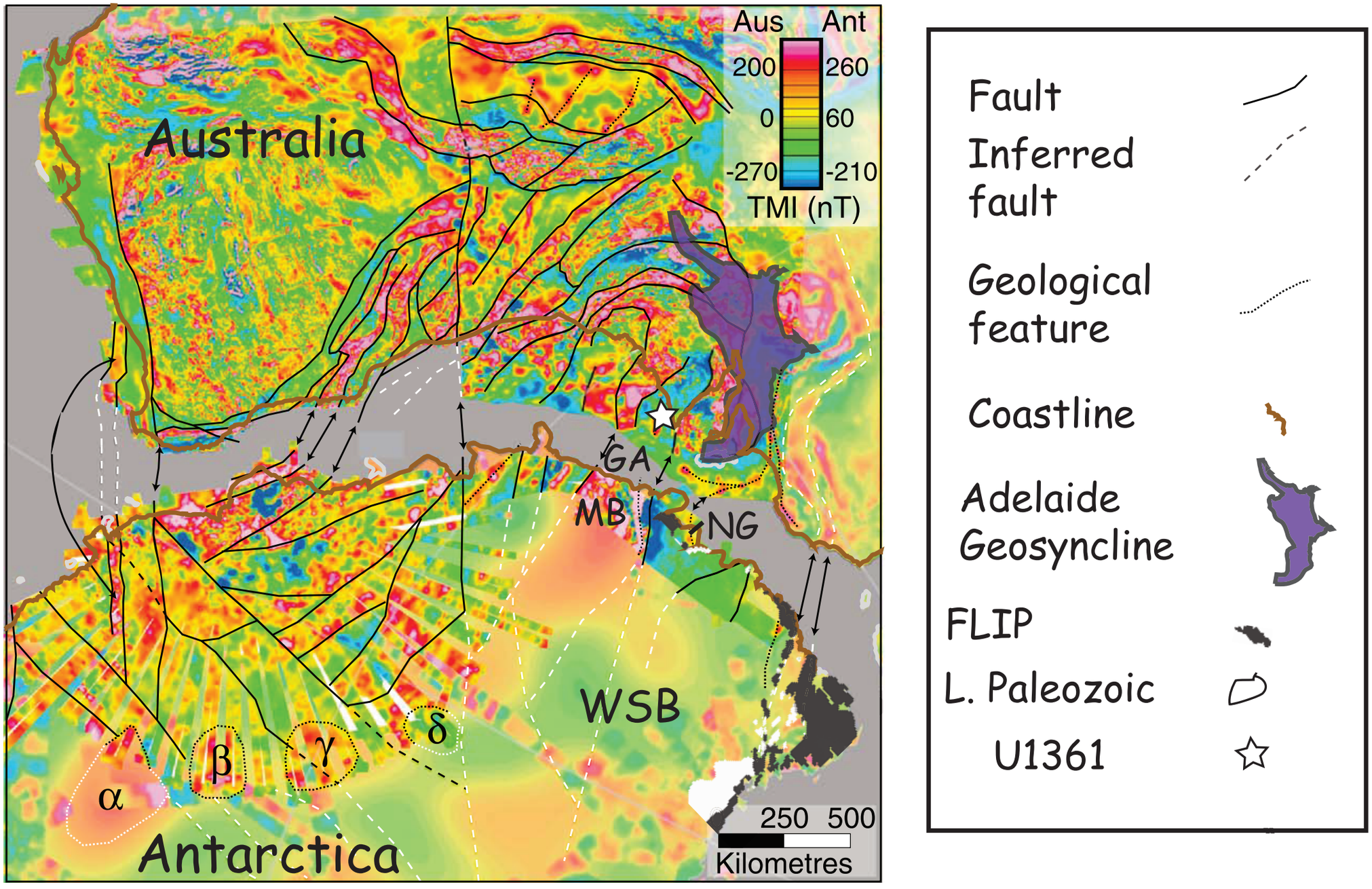
Green: found in “bioturbated silty clay” units (warm): Type 2

So what are the “hard” layers? (Type 3)

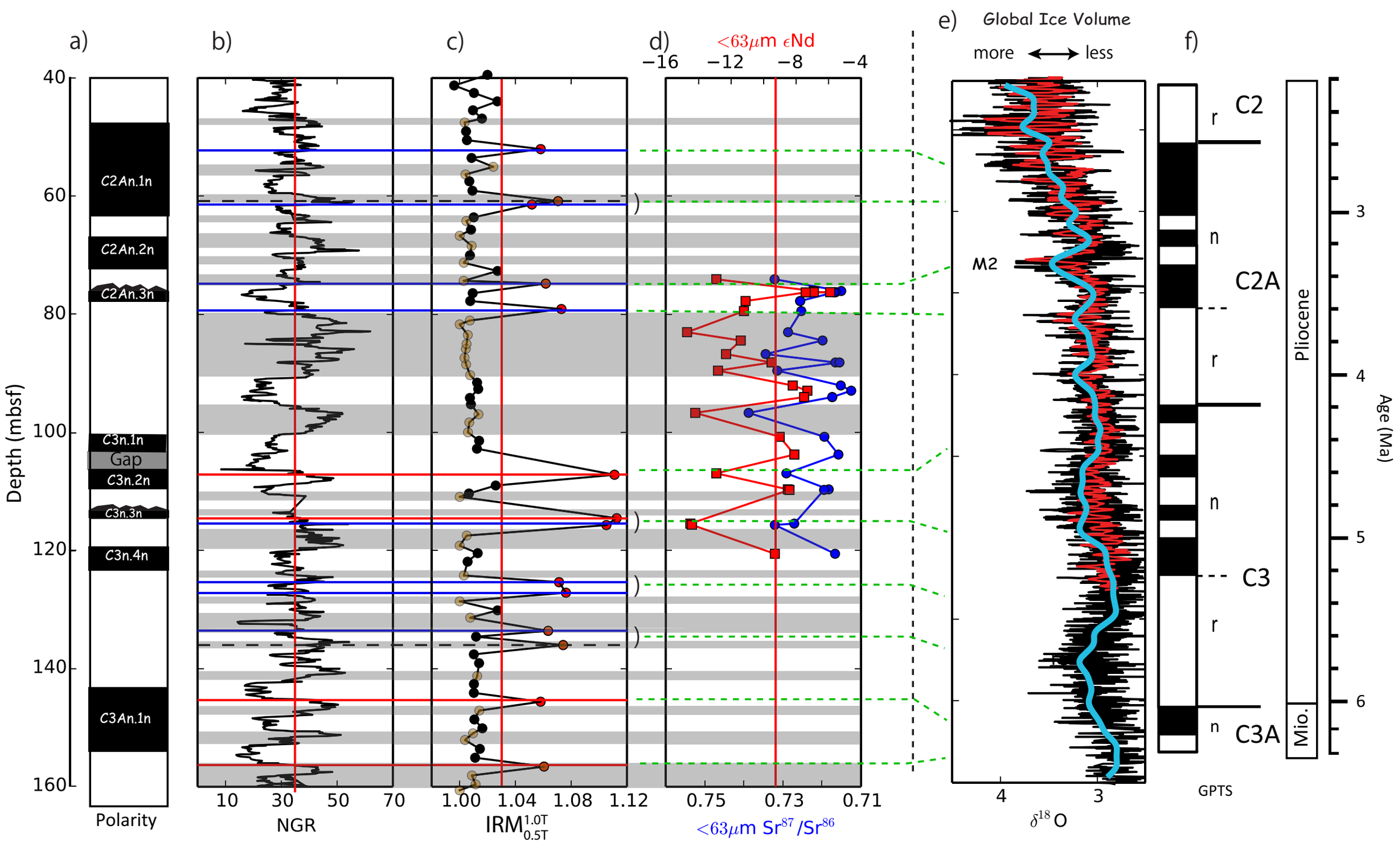
What is the source of the “hard” layers?

- Mawson(1915)(vol.2, p.294) wrote: “Stillwell met with a great range of minerals and rocks in the terminal moraine near Winter Quarters, Adelie Land. Amongst them was red sandstone in abundance, suggesting that the Beacon sandstone formation extend also throughout Adelie Land, but is hidden by the ice-cap.”
- Alternatively, there are red beds in the Elatina Formation in the Adelaide Basin of Australia

Reconstruction of Aitken et al. (2014) with location of Adelaide geosyncline which has the Elatina formation. Schmidt and Williams (2013) found hematite there.



Elatina could be under ice on Antarctica and be source of hematite when ice volume was higher than other times (closer to the coast)



- Hematite layers only found between facies and mostly when global ice volume was relatively high.

Tauxe et al.,2015 see also Patterson et al.,2014

Conclusions

- AMS is sensitive indicator of clay fraction at Hole U1361A.
- High anisotropy = low productivity (colder climate)
- Low anisotropy = higher productivity and warmer climate
- Different magnetic mineralogies are tied to different geological units and support argument in favor of a very active East Antarctic Ice Sheet during the Pliocene.
- Presence of hematite in the detrital fraction points to Elatina or Beacon sandstone units under the ice between the lower Paleozoic and the FLIP units.