VIII GeoSciEd 2018 – 8th Quadrennial Conference of the International Geoscience Education Organisation (IGEO)
– Geosciences for Everyone –
VIII Simpósio Nacional de Ensino e História de Ciências da Terra / EnsinoGEO-2018
– Geociências para Todos –
Campinas – Sao Paulo – Brazil, July 2018

Geology & relief of South America: Phanerozoic seas, glaciers, deserts...

Celso Dal Ré Carneiro

Graduate Program of Teaching and History of Earth Sciences
Geosciences Institute

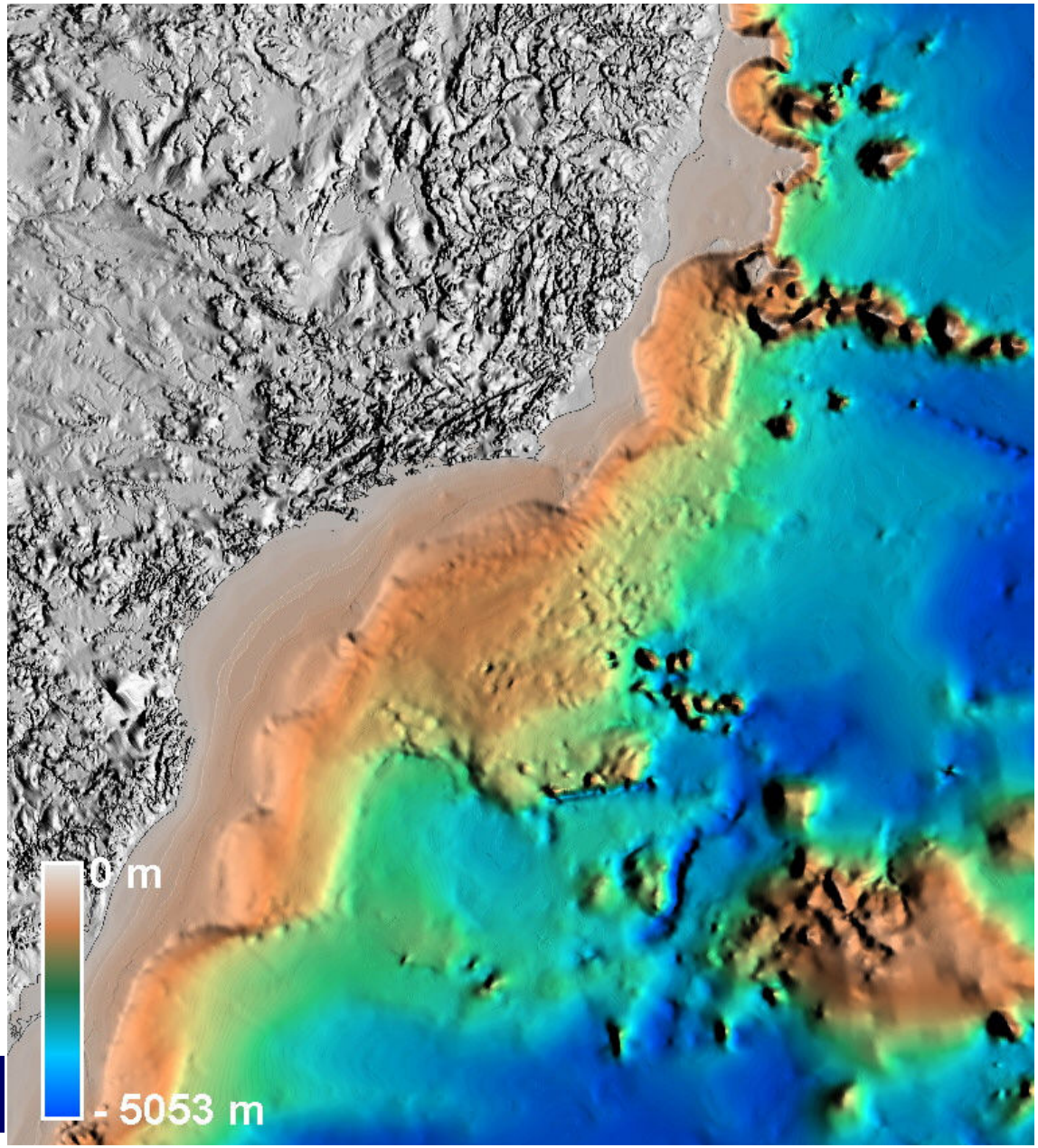
University of Campinas

International Geological Monument

Great News!

Pre-Salt,

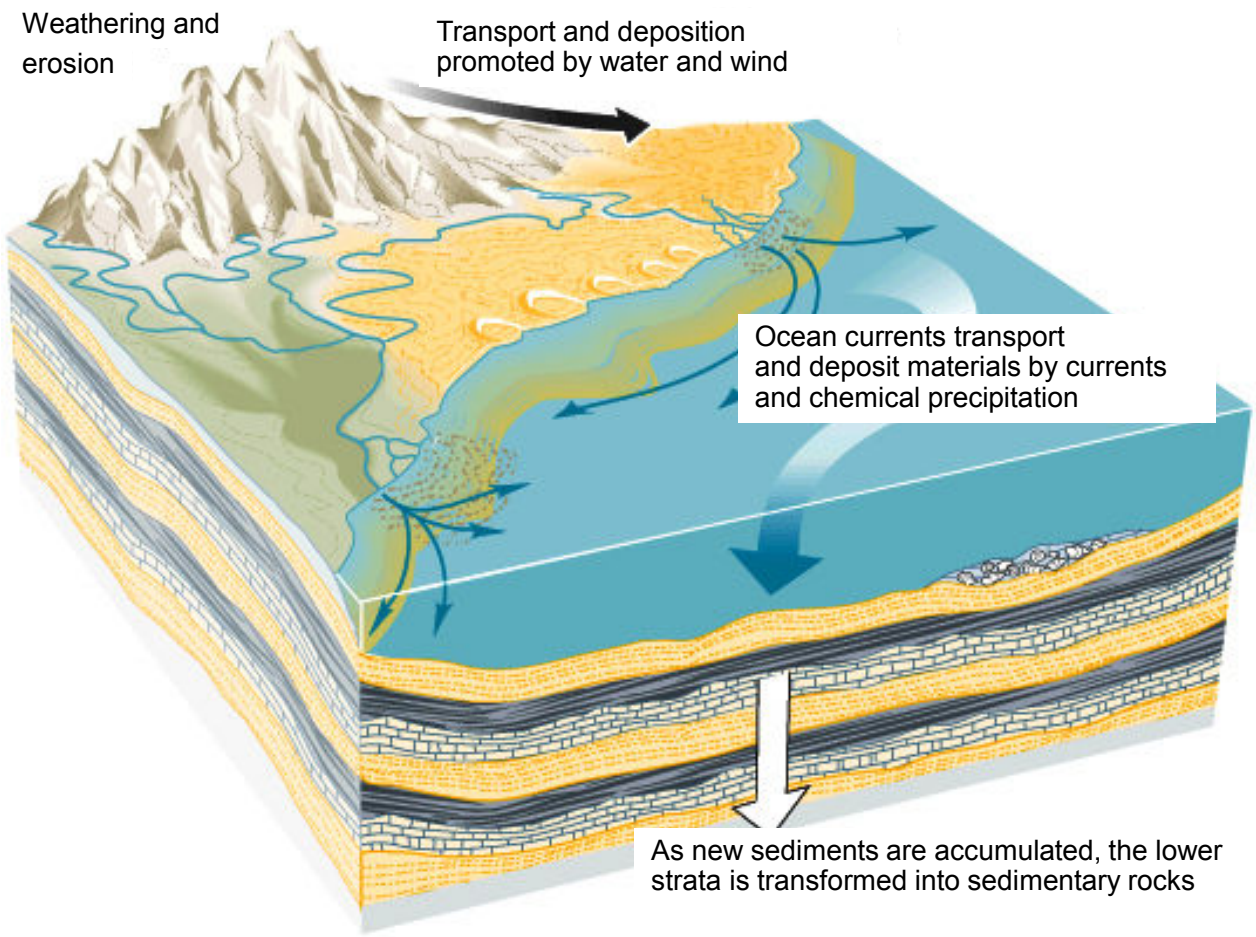
how to explain the origin of it?



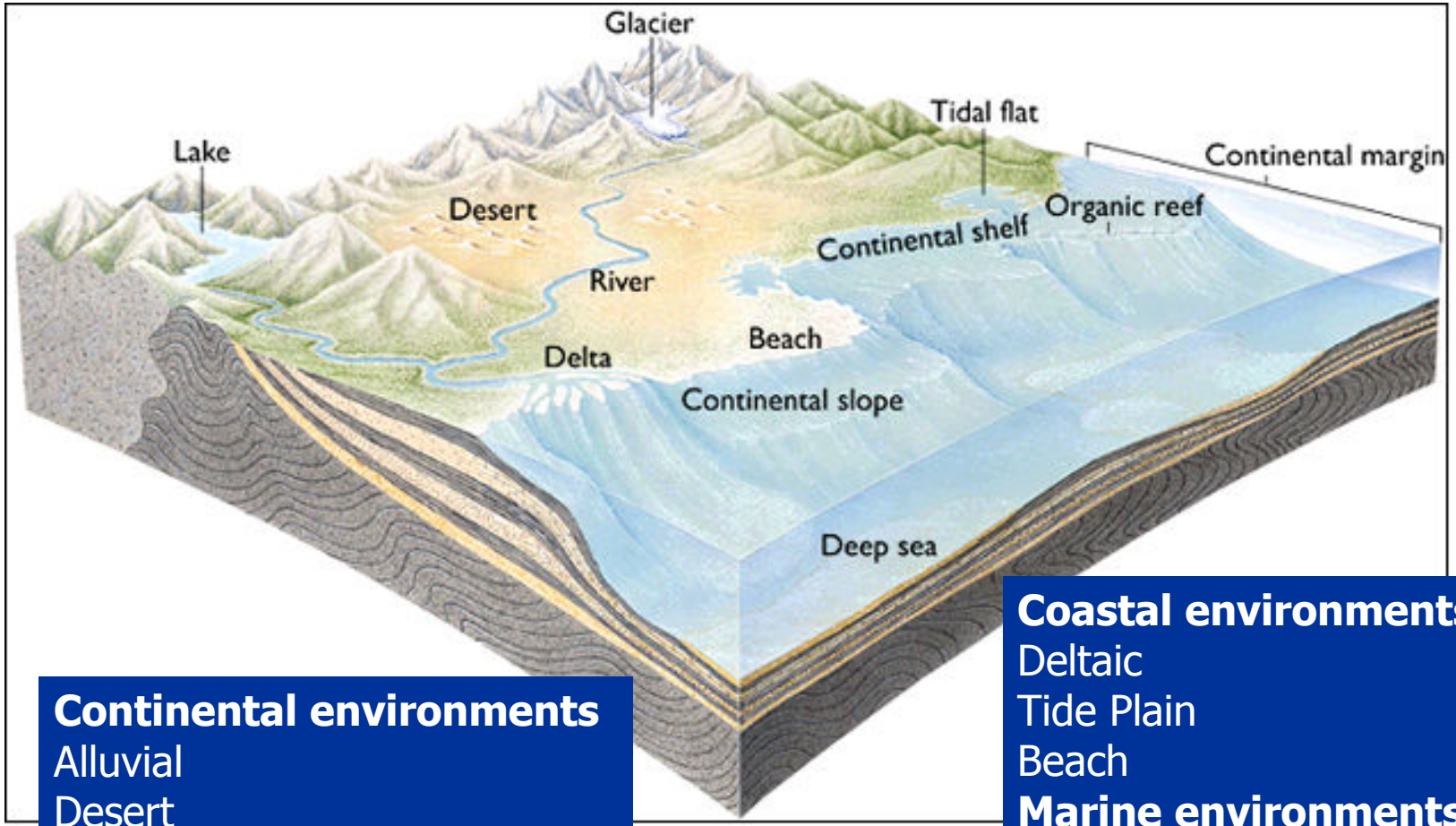
Topo-bathimetry and relief of Southeastern South America (Mohriak 2004, modif. C. Bentz)


The present is key to the past...
Sir Archibald Geikie (1897)

How do sedimentary rocks form?



http://conteudodasprovas.wordpress.com/category/ciencias/



Continental environments
Alluvial
Desert
Lake
Glacial

Coastal environments
Deltaic
Tide Plain
Beach

Marine environments
Continental platform
Continental slope
Organic reefs
Deep sea

Presentation objectives

- A review of basic concepts
  - Elements of Plate Tectonics
  - South American Geology
    - Origin of basement rocks (Proterozoic)
  - Evolution of sedimentary basins, focusing on the Parana Basin
    - Giant mafic volcanism (Lower Cretaceous)
      - Relationship with break-up of tectonic plates
  - Relief of South America
- Sharing ideas and proposals for the classroom

Brazil and its continental geographical expression, its complex but still unknown Geology, (...) have an infinite horizon of applied research

Geologia Humana, 2018, Luis Manoel Siqueira

Image credits

ALMEIDA, F. F. M. de 1986. Distribuição regional e relações tectônicas do magmatismo pós-Paleozóico no Brasil. *Revista Brasileira de Geociências* **16**(4).

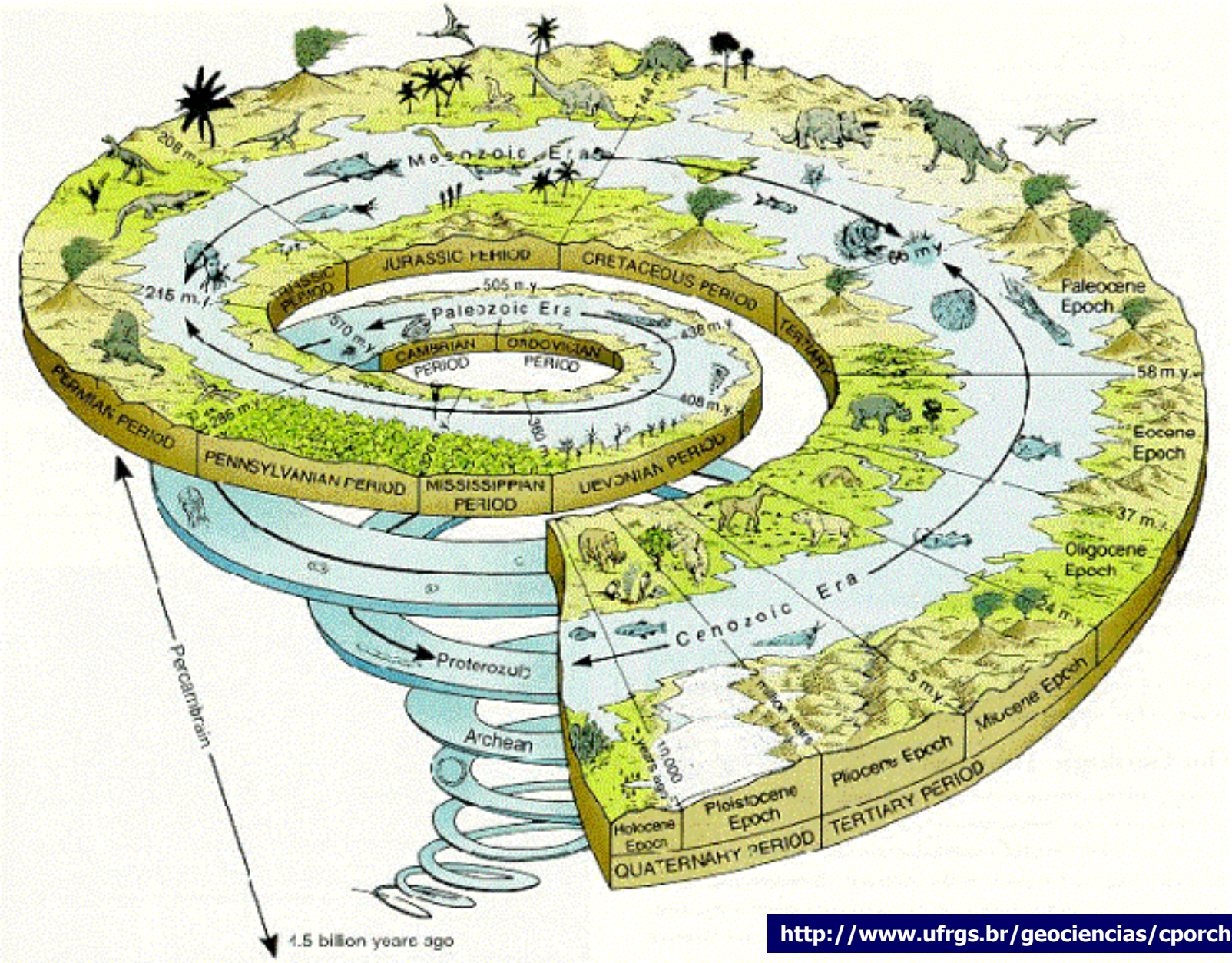
GABAGLIA G.P.R. & MILANI E.J. coords. 1991. *Origem e evolução de bacias sedimentares*. Rio de Janeiro. PETROBRÁS. p. 361-374.

HASUI Y., et al. (eds.). 2012. *Geologia do Brasil*. São Paulo: Ed. Beca. 900p.

MANTESSO-NETO et al. (eds.). 2004. *Geologia do Continente Sul-Americano*: *Evolução da Obra de Fernando Flávio Marques de Almeida.*

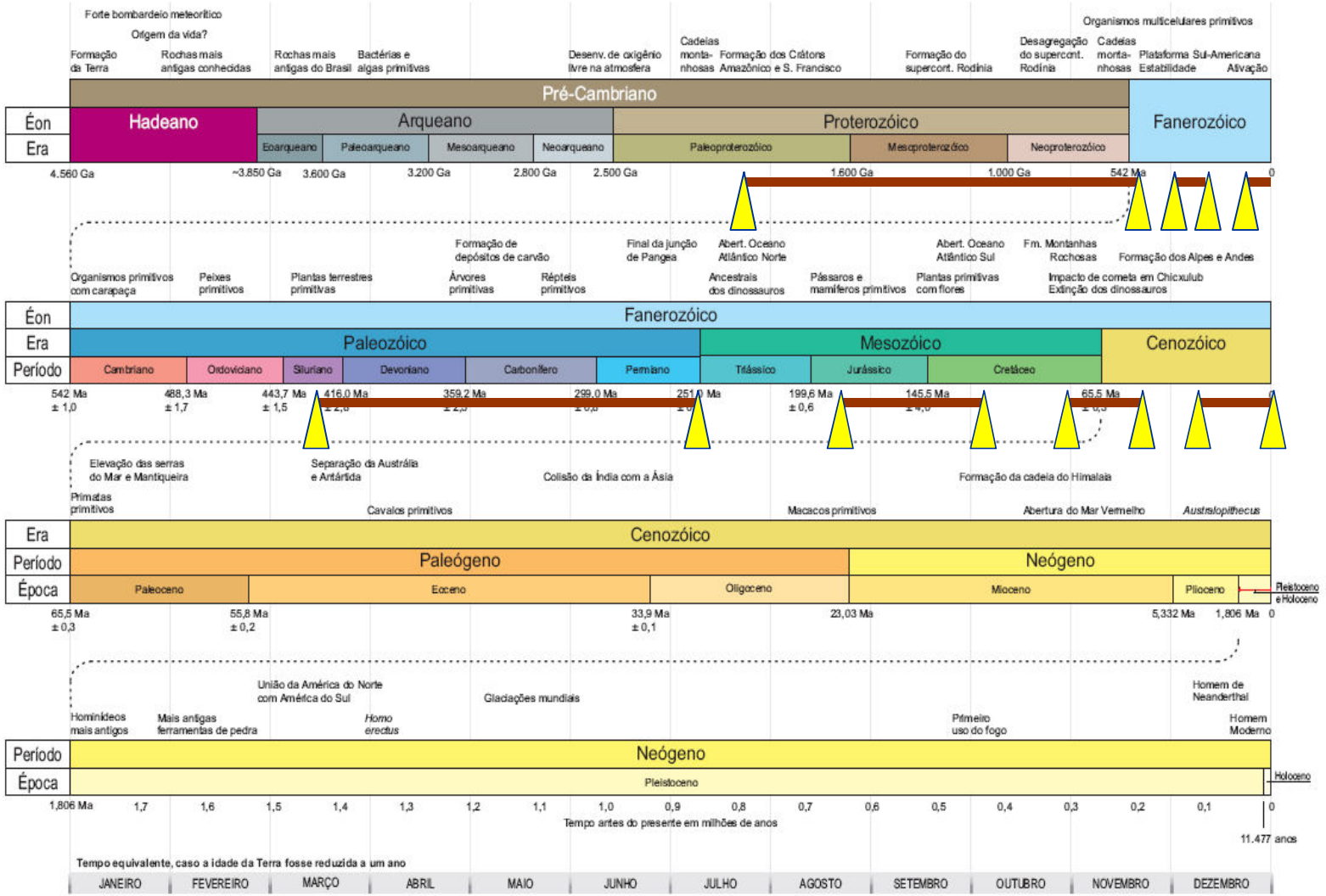
Geologic Time Scale

Putting events on time order...

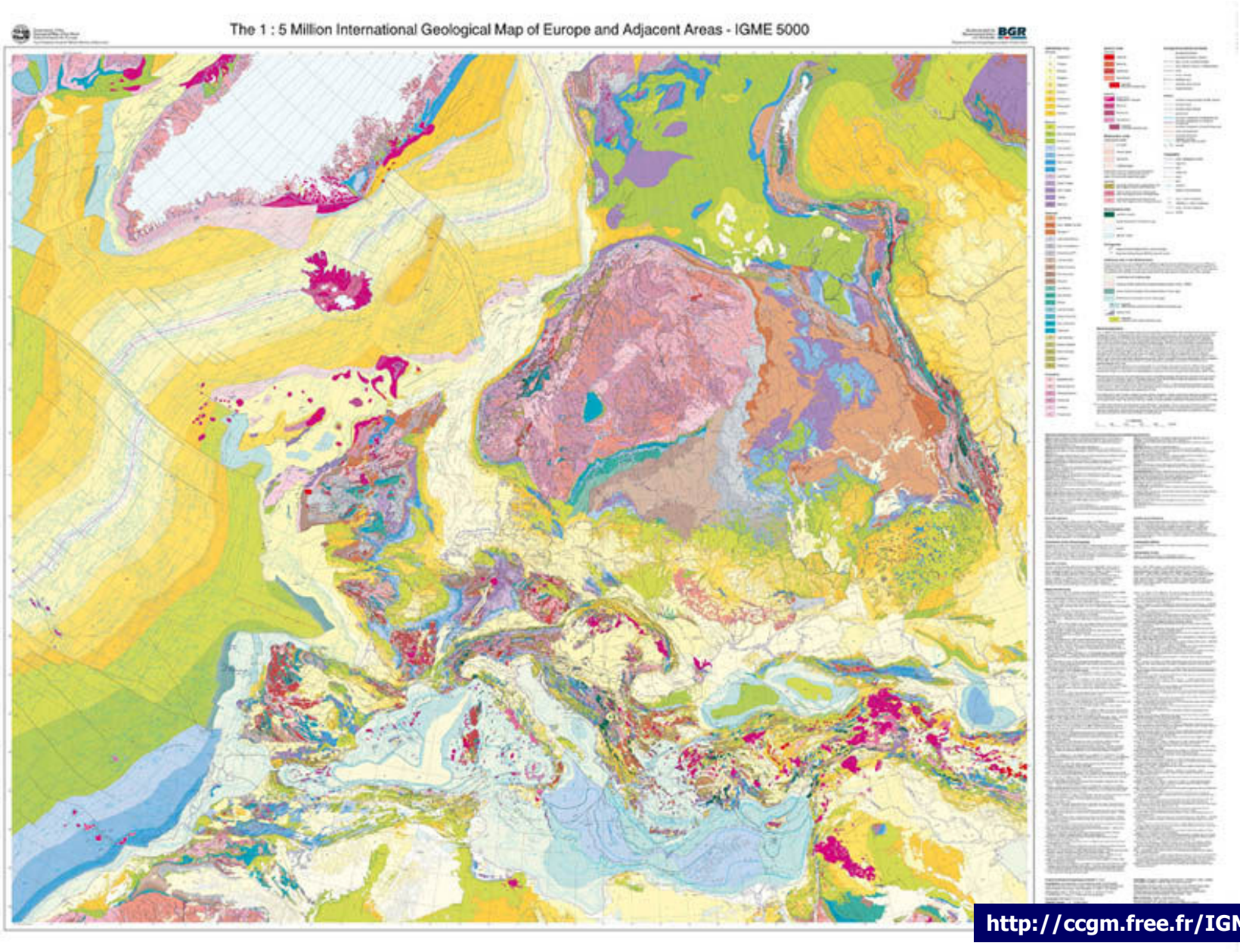


http://www.ufrgs.br/geociencias/cporcher/.../image034.gif

Geologic Time Scale, 2004: time intervals of interest

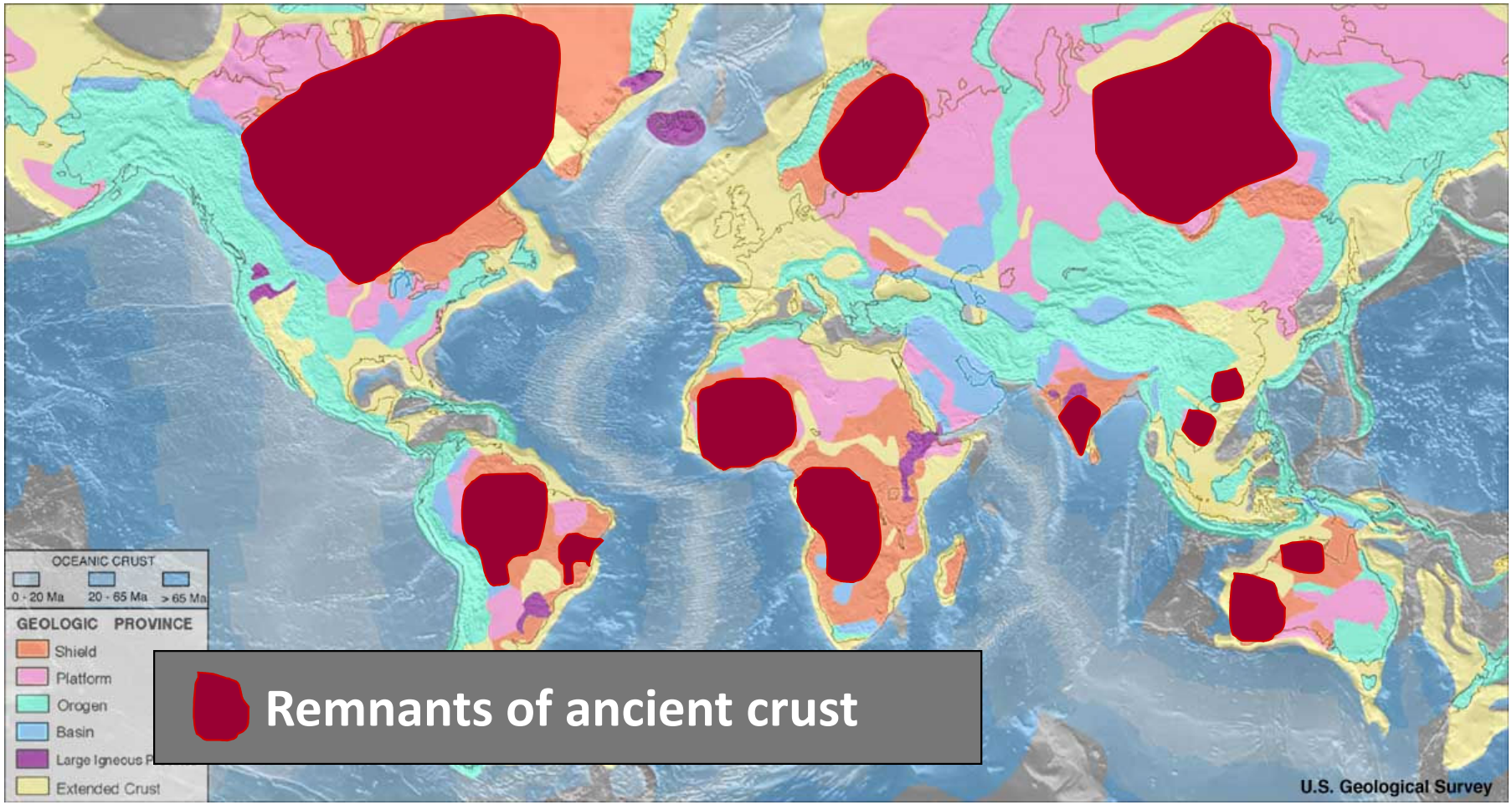


Fontes e siglas: Ga (giga-age) = bilhão de anos; Ma (mega-age) = milhão de anos. Arte baseada em *The Dynamic Earth*, de R. Siever. *Scientific American*, 1983. Escala do Tempo Geológico: Gradstein F.M. et al. 2004. A New Geologic Time Scale, with special reference to Precambrian and Neogene. *Episodes*, 27(3):83-100. Padrão de cores CMYK: The Geologic Data Subcommitee (GDS). Federal Geographic Data Commitee (FGDC). 2007. FGDC Digital Cartographic Standard for Geologic Map Symbolization. Acesso em 11.06.2007. Maintained By Dave Soller. Last Updated: 04-27-07. <Http://ngmdb.usgs.gov/fgdc_gds/geolsymstd.php>. Fonte de consulta web: Carneiro C.D.R., Mizusaki A.M.P., Almeida F.F.M.de. 2005. A determinação da idade das rochas. *Terrae Didatica*, 1(1):6-35. <http://www.ige.unicamp.br/terraedidatica/v1n1/t_didatica_2005_v01n01_p008-035_carneiro.pdf>. Produção gráfica: João Cláudio Toniolo. Supervisão: Celso Dal Ré Carneiro. 2007. UNIVERSIDADE ESTADUAL DE CAMPINAS. Instituto de Geociências. Departamento de Geociências Aplicadas ao Ensino.



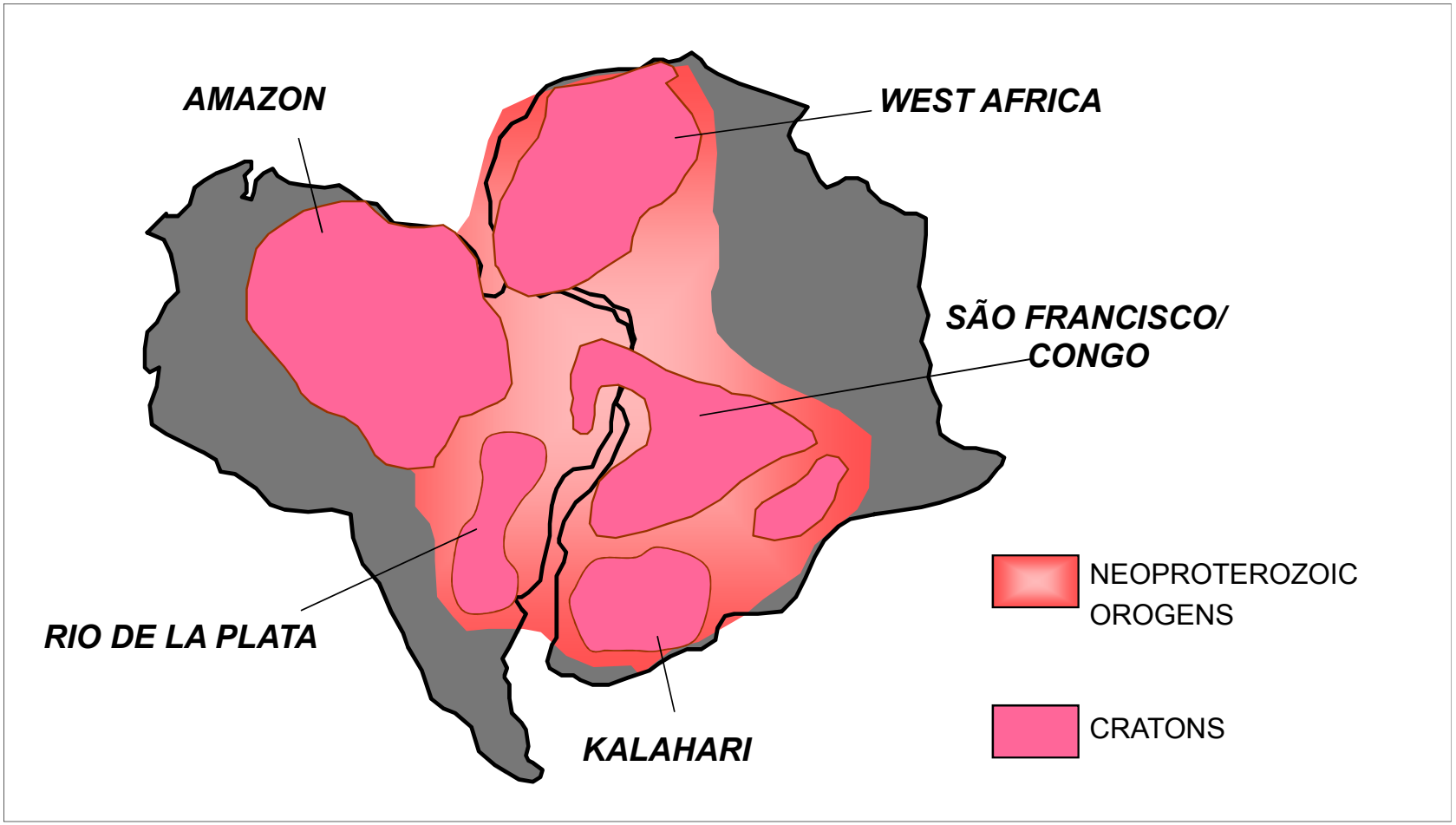
http://ccgm.free.fr/IGME_image_gb.html

Where are the ancient platforms of the globe?



http://upload.wikimedia.org/wikipedia/commons/a/a9/World_geologic_provinces.jpg

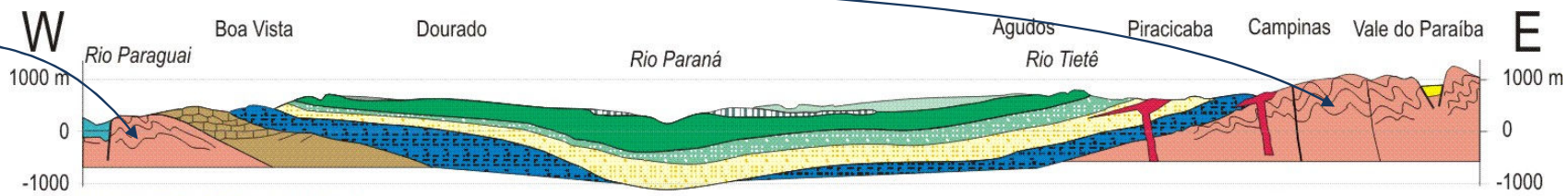
Cratons composing Gondwanaland

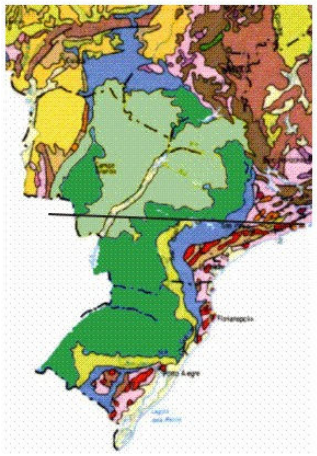



Relief of South America
A cut of **South America** along the red line would yield a profile like the following slide

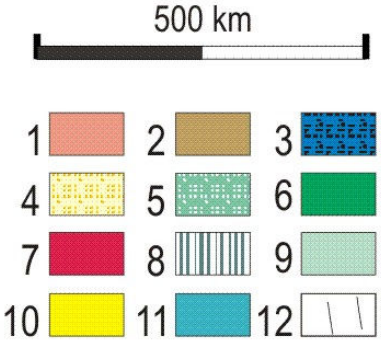
Geologic profile

Ancient thrust-and-fold belts



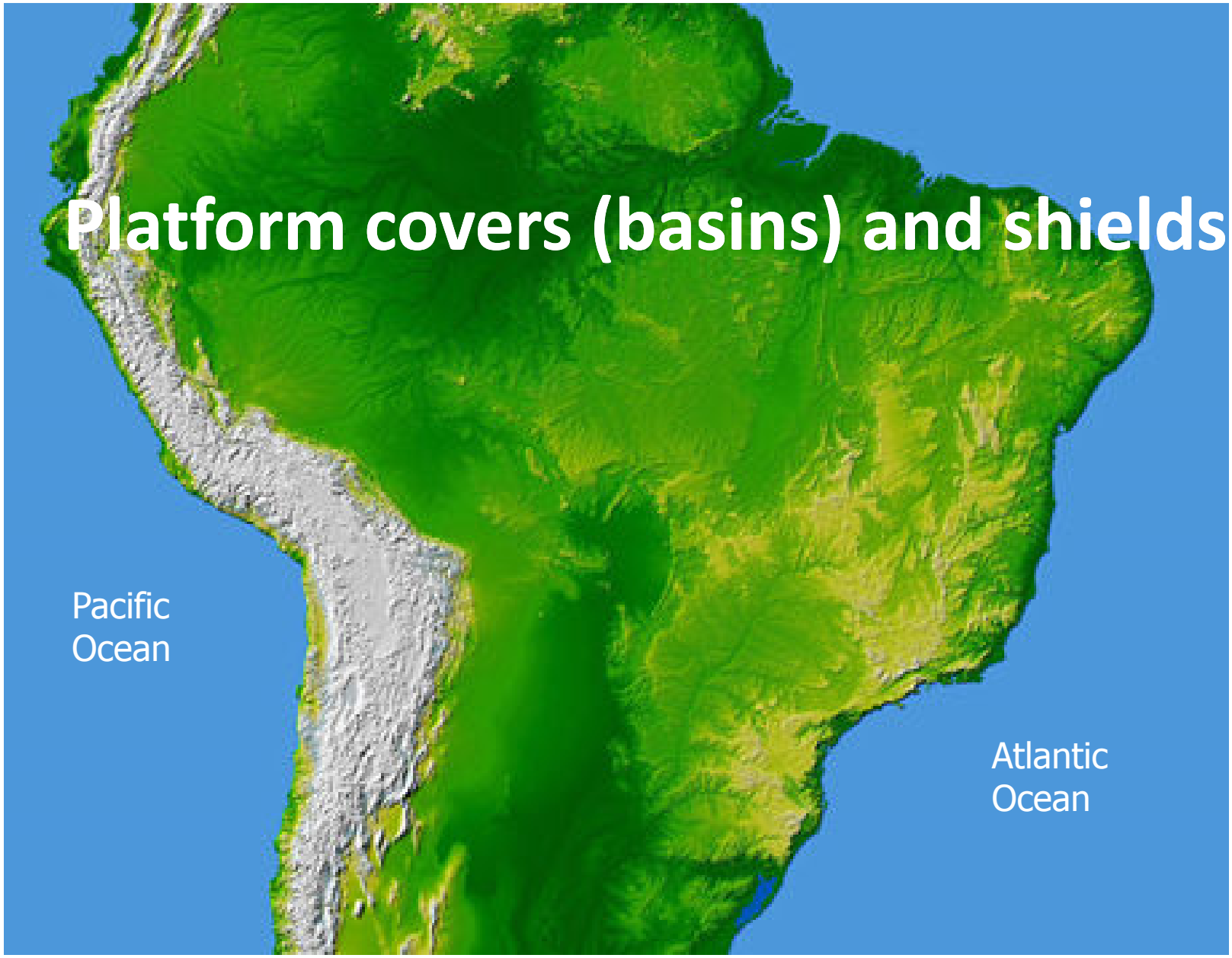


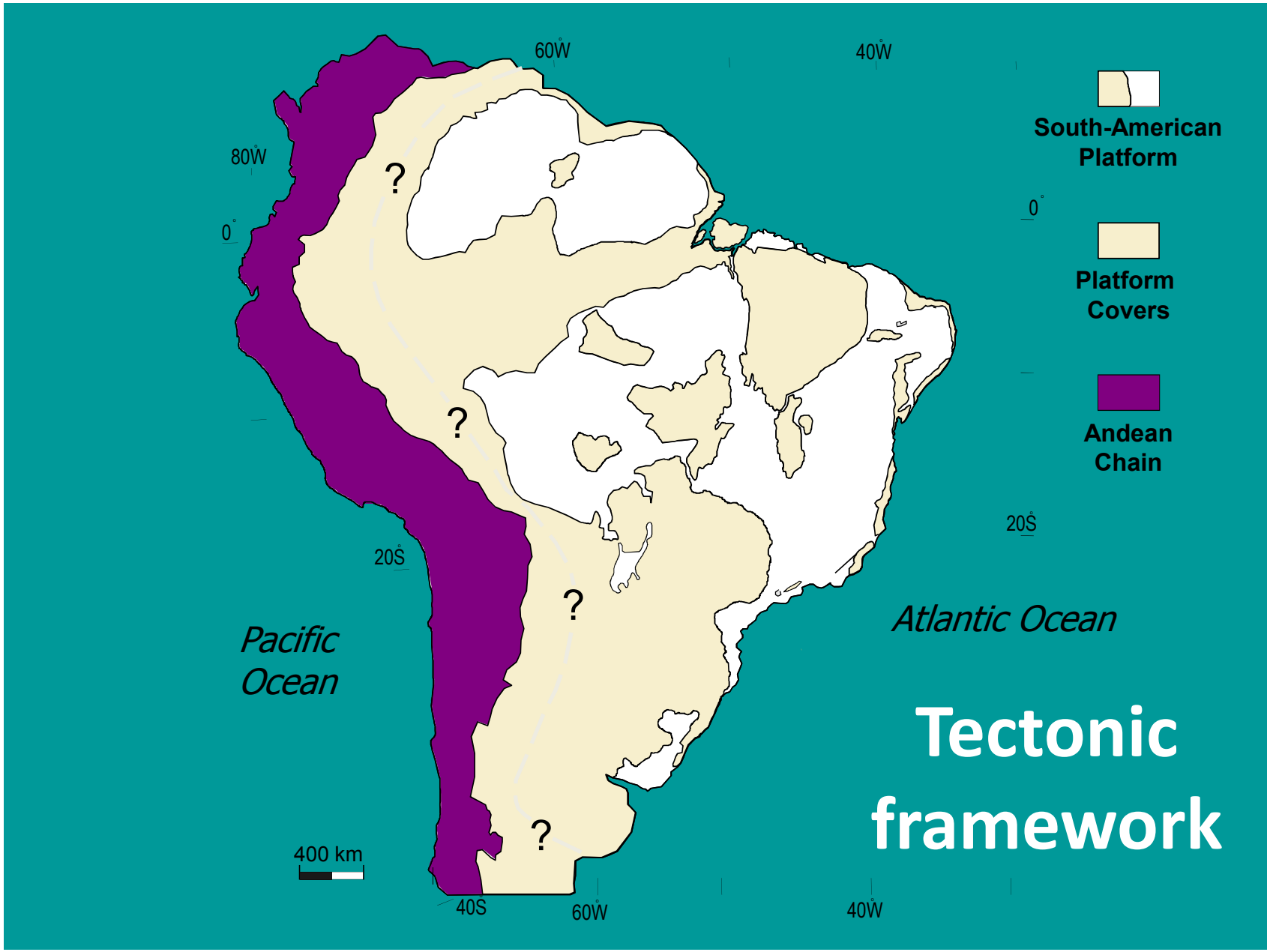
1. Embasamento Cristalino
2. Grupo Serra da Bodoquena, calcários
3. Formação Aquidauana (W) e Grupo Tubarão (E) - glacial e pós-glacial
4. Formação Independência (W) e Grupo Passa Dois - marinho
5. Formações Pirambóia e Botucatu - arenitos fluviais a desérticos
6. Formação Serra Geral - basaltos de inundação
7. Intrusivas básicas
8. Grupo Caiuá - arenitos fluviais
9. Grupo Bauru - arenitos fluviais
10. Sedimentos terciários
11. Sedimentos quaternários
12. Falhas



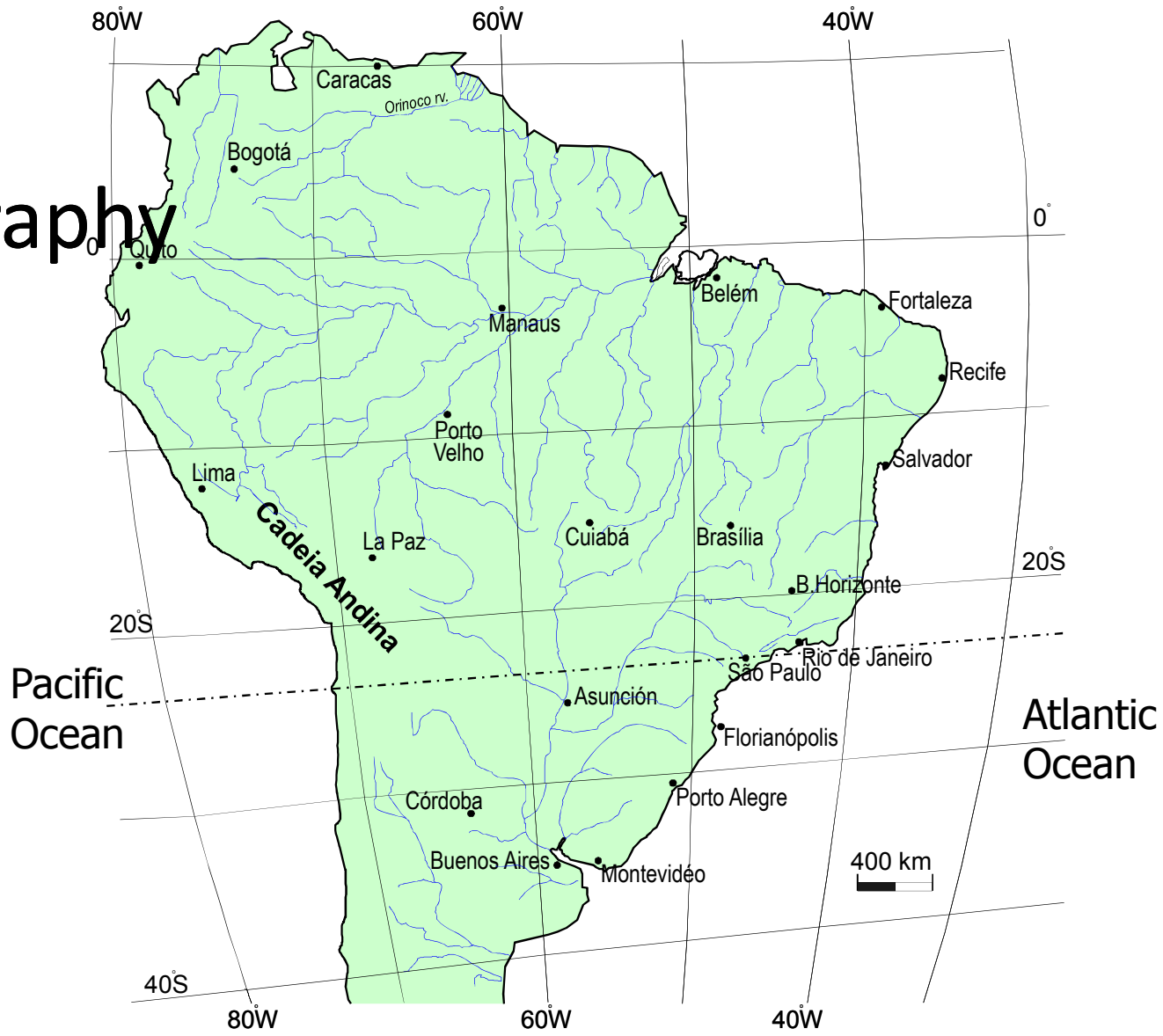
1-2 = Exposed basement (shields)

3-11 = Platform covers


Platform covers (basins) and shields
Pacific
Ocean
Atlantic
Ocean

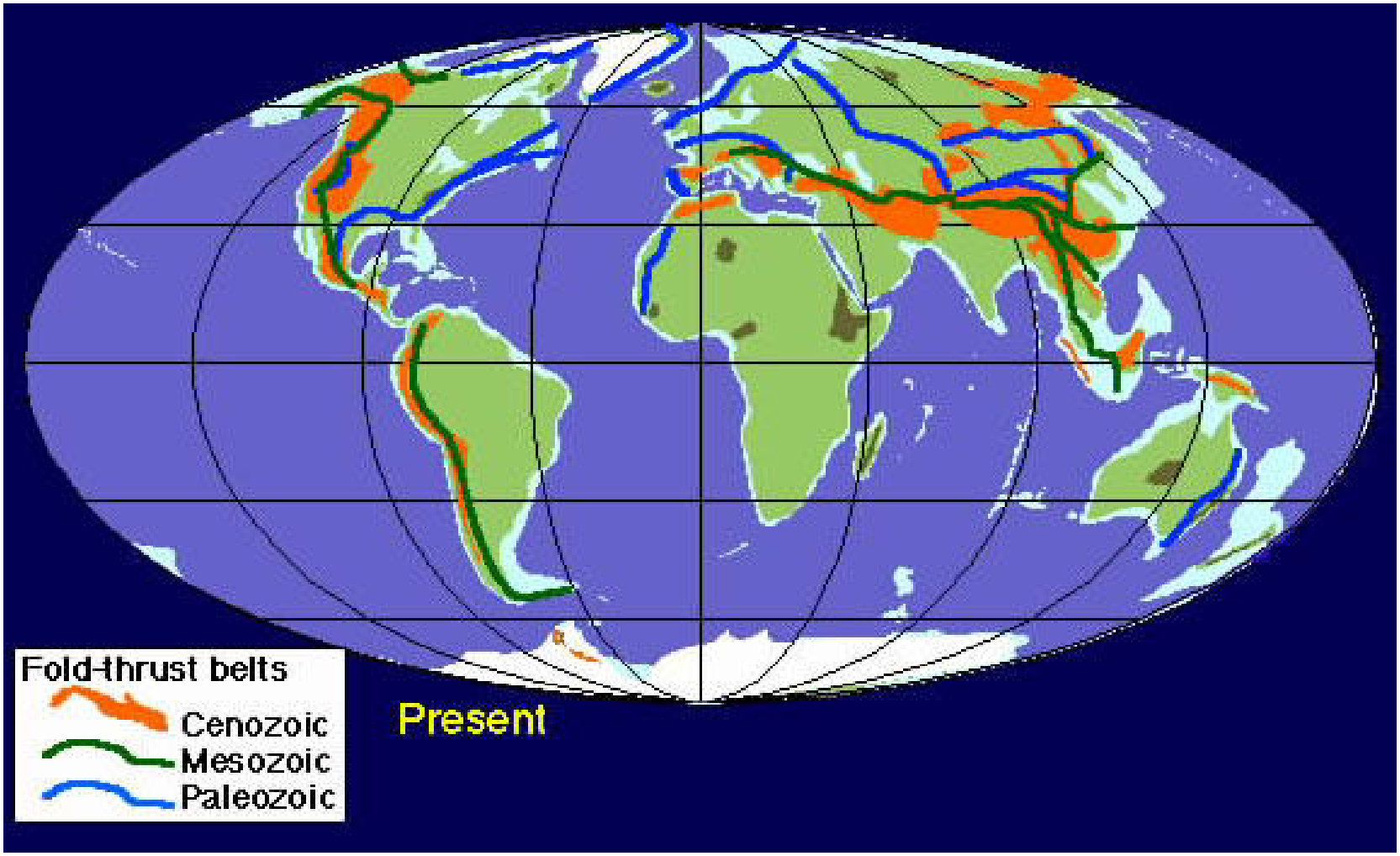

60W
40W
80W
0
20S
40S
?
?
?
?
South-American Platform
Platform Covers
Andean Chain
Pacific Ocean
Atlantic Ocean
400 km
Tectonic framework

Hydrography




Anti-Atlas Mountains near Tilemsoun, Morocco
Tilemsoun
Subduction zones and collision of tectonic plates
FOLDS ACCOMMODATE STRAIN IN THE EARTH'S CRUST
http://serc.carleton.edu/NAGTWorkshops/structure/google_earth_mapping_locations.html

Orogens are linked to the limits of lithospheric plates

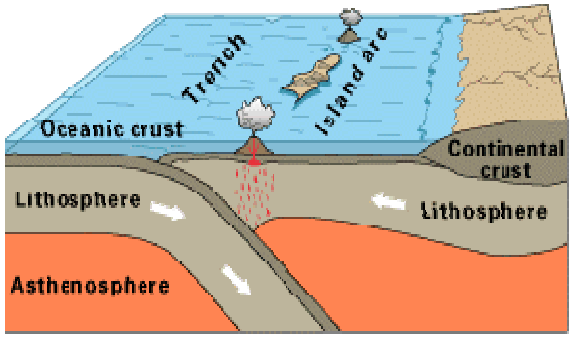


Many continental structures are controlled by folds…

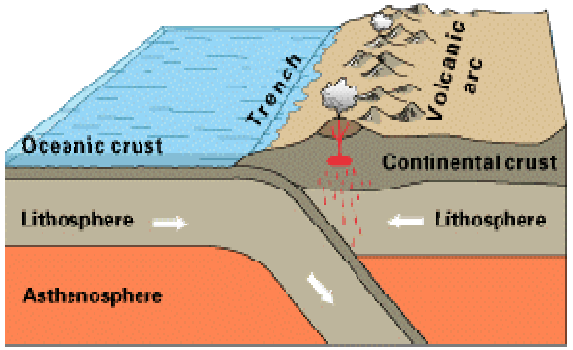
Folds south of In Salah, Algeria, https://serc.carleton.edu/NAGTWorkshops/structure/google_earth_mapping_locations.html

Types of tectonic convergence

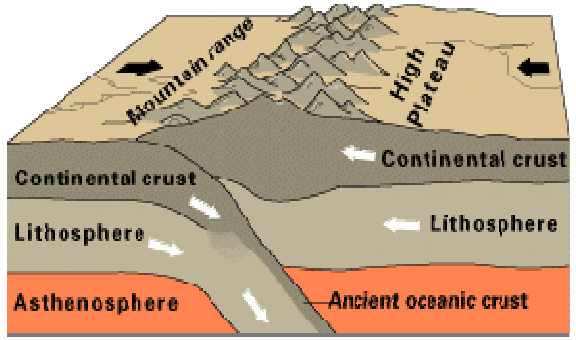
- Subduction
  - Lithosphere
    - **Ocean X Ocean**
    - **Ocean X Continental**
- Collision
  - Lithosphere
    - **Continental X Continental**



Oceanic-oceanic convergence

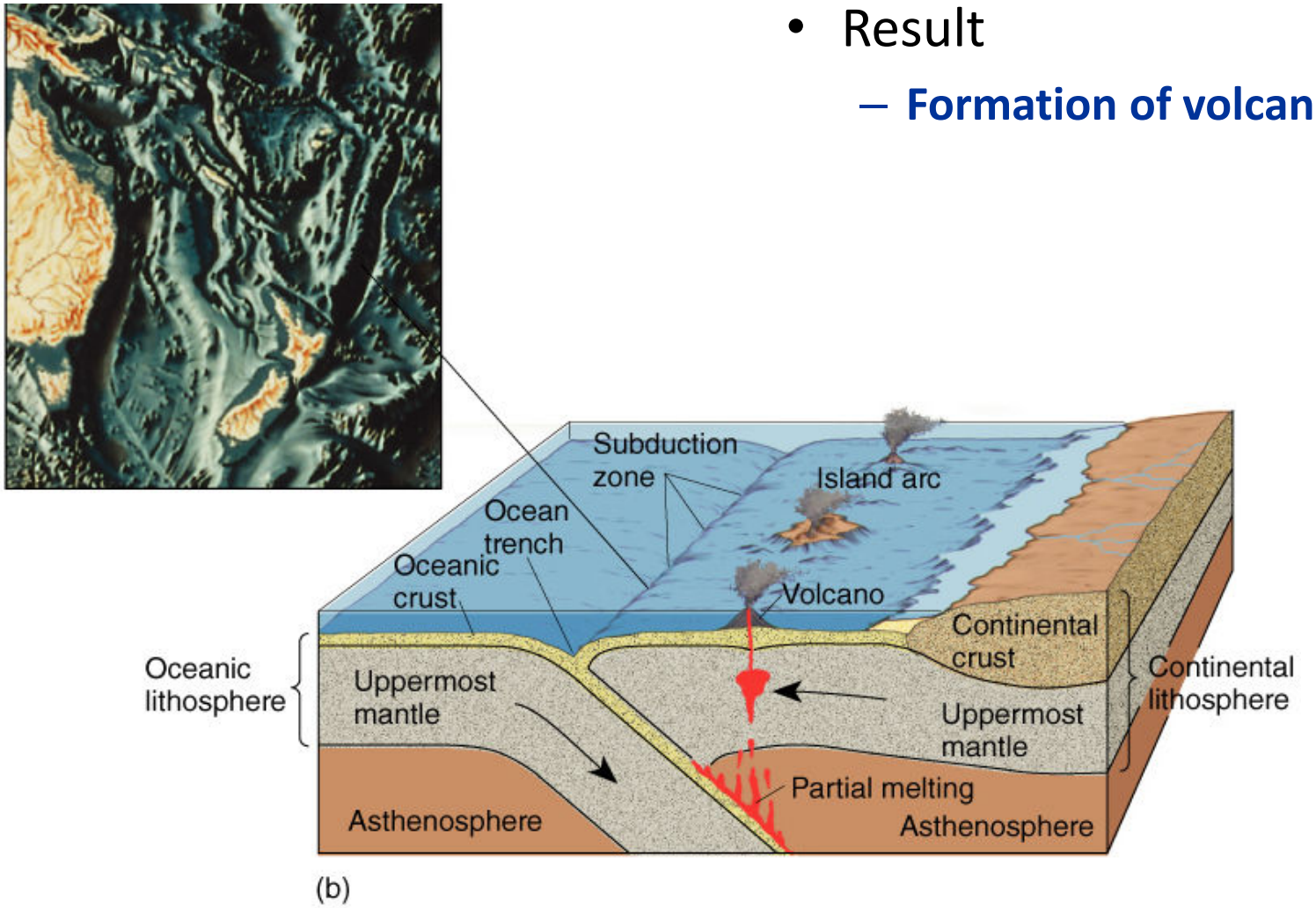


Oceanic-continental convergence

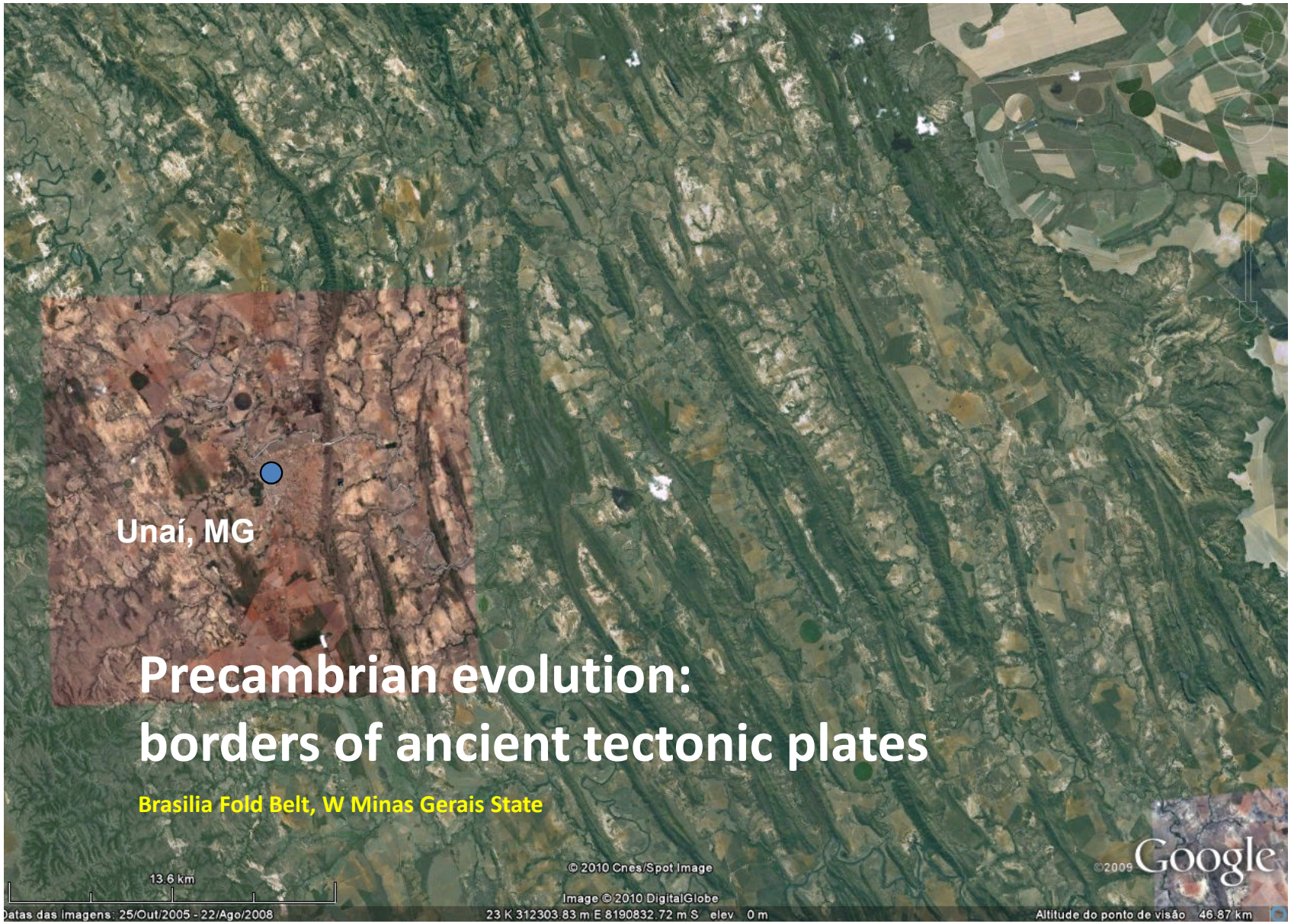


Continental-continental convergence

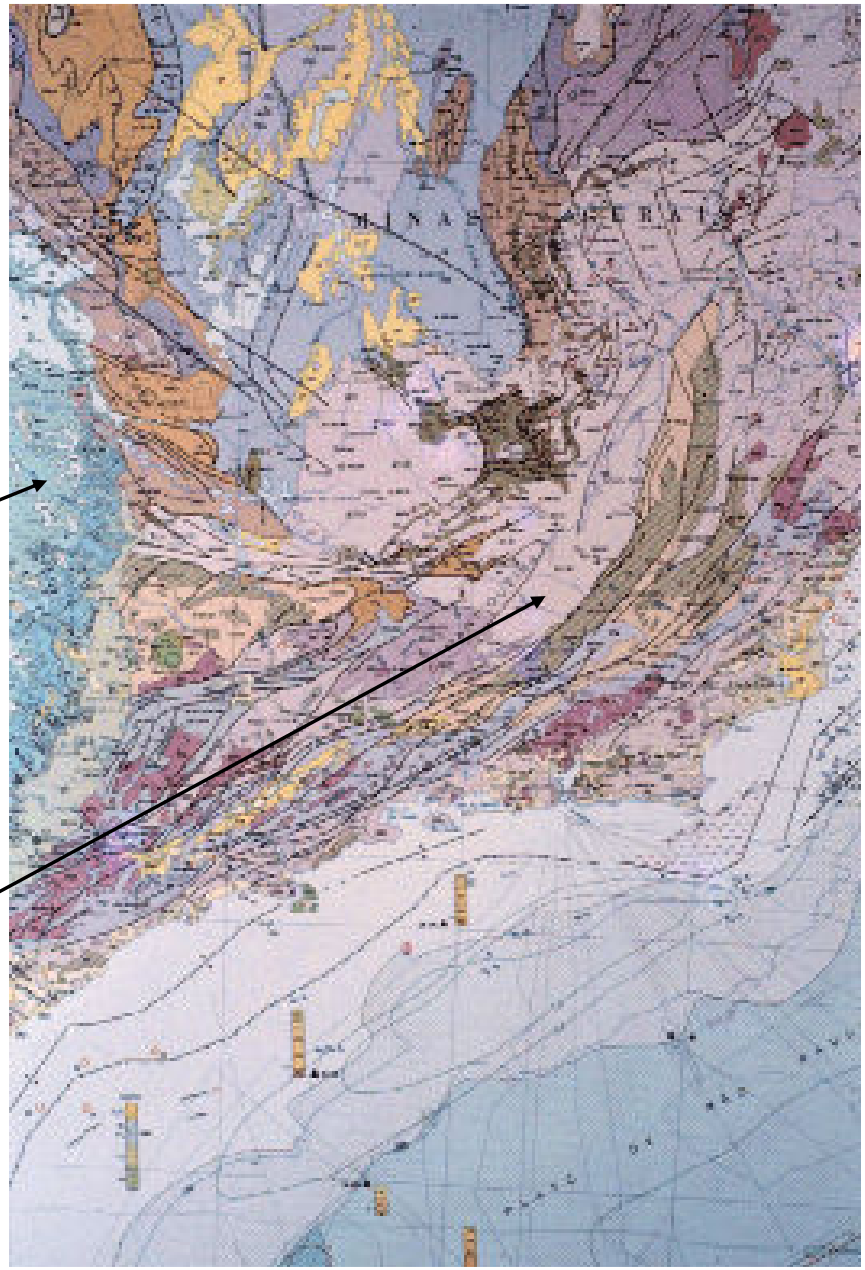
Subduction: ocean-ocean plates



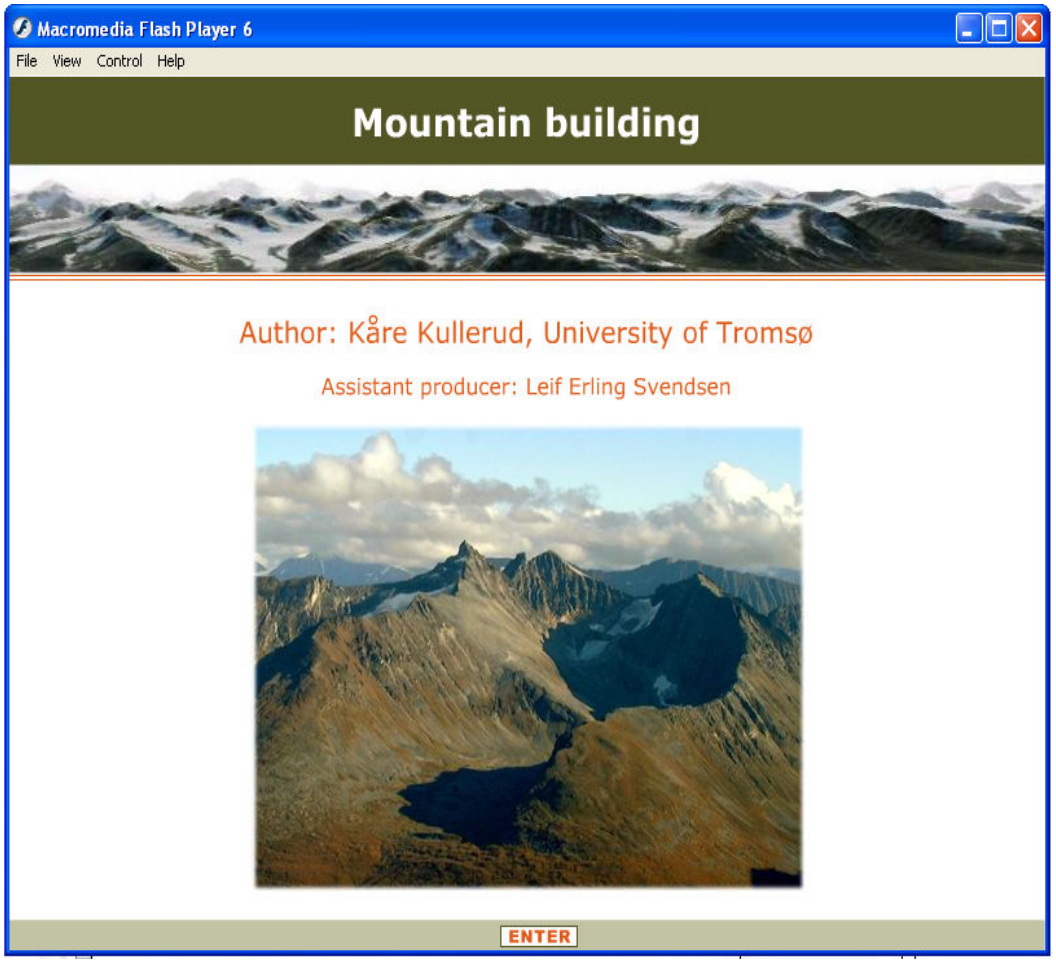
- Result
  - **Formation of volcanic island arcs**


Unaí, MG
Precambrian evolution:
borders of ancient tectonic plates
Brasilia Fold Belt, W Minas Gerais State
13.6 km
© 2010 Cnes/Spot Image
Image © 2010 DigitalGlobe
©2009 Google
Datas das imagens: 25/Out/2005 - 22/Ago/2008
23 K 312303.83 m E 8190832.72 m S elev 0 m
Altitude do ponto de visão 46.87 km

Structure of a region: south of MG, SP-RJ



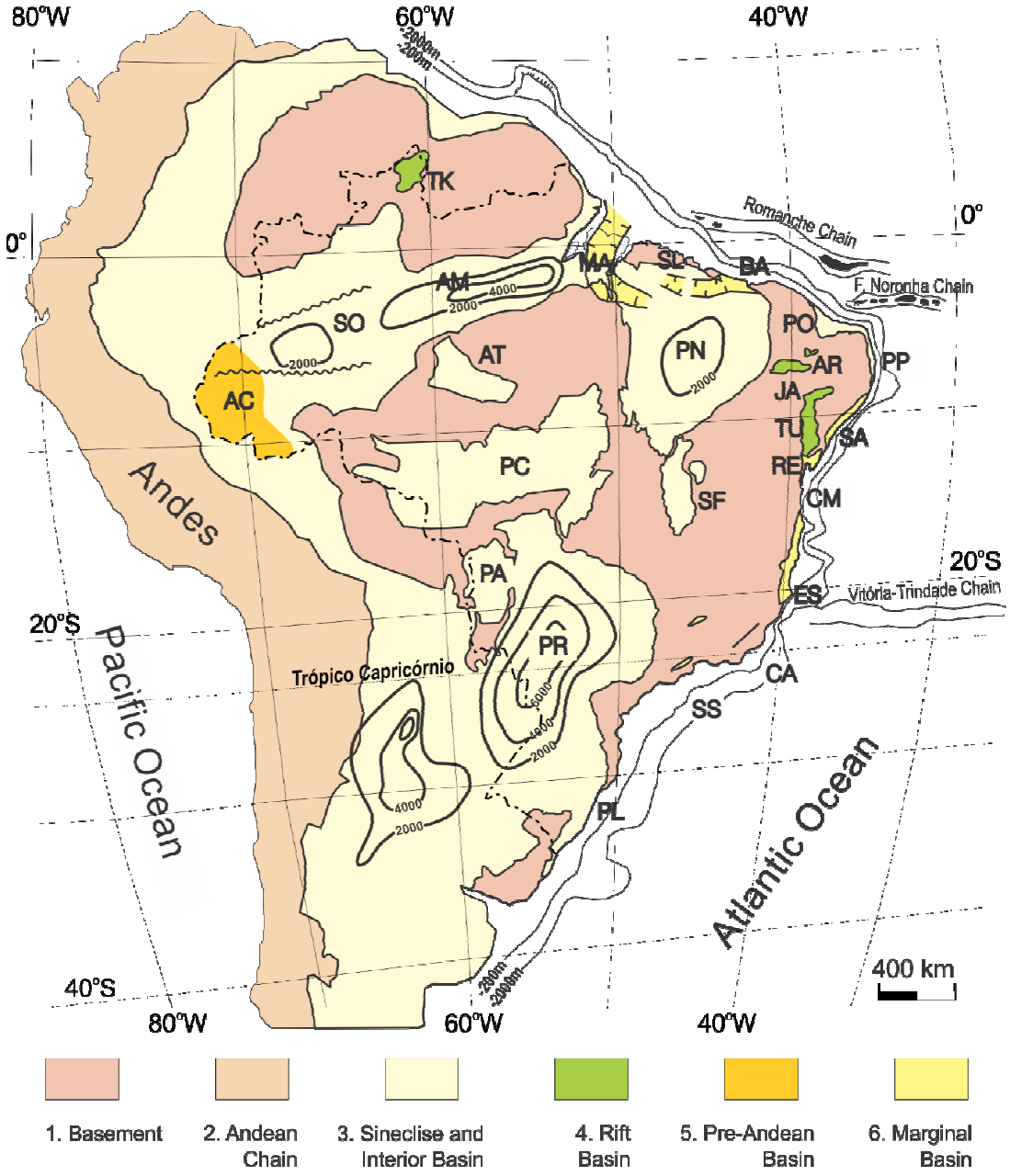
Animation mountains.swf



Source http://www.geographyalltheway.com/in/gcse-plate-tectonics/imagesetc/mountains.swf

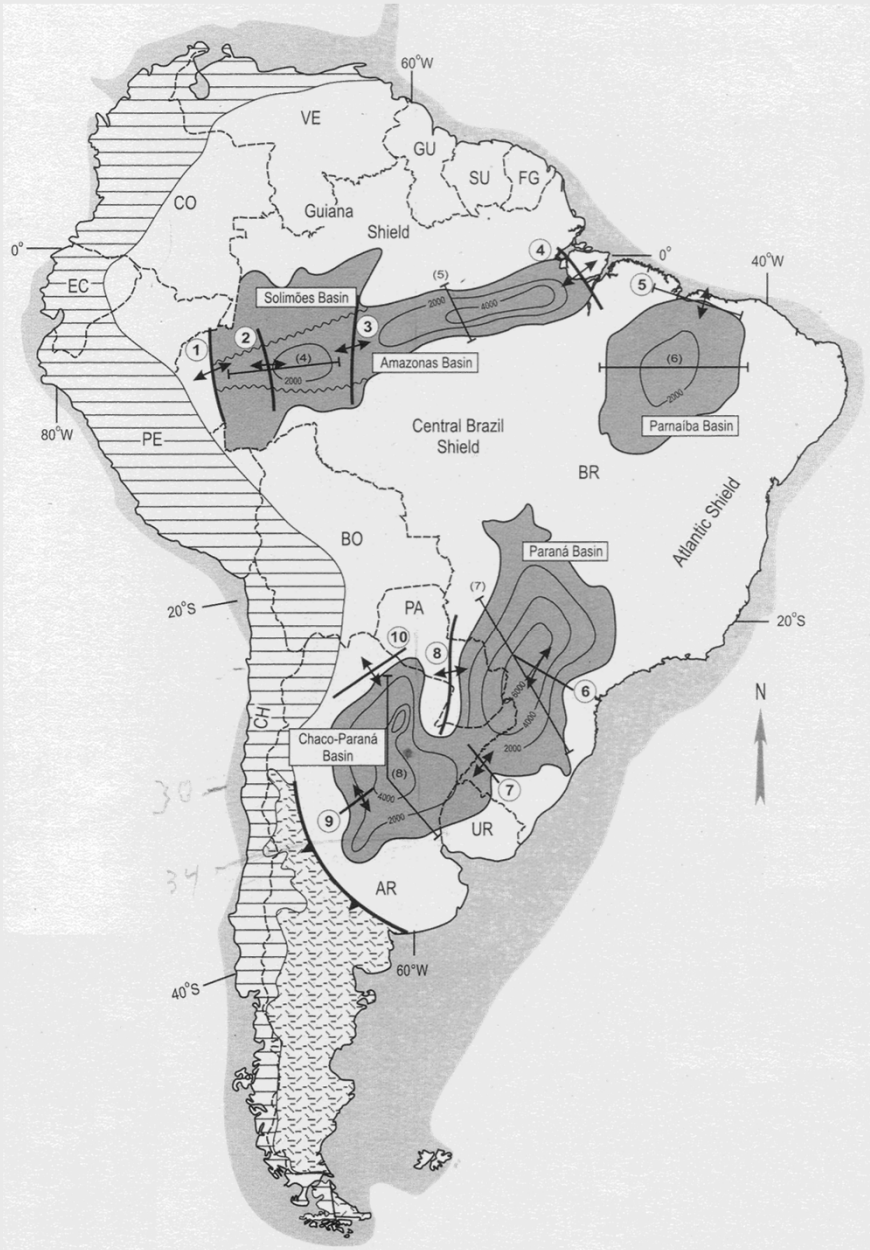
Geology & relief of South America

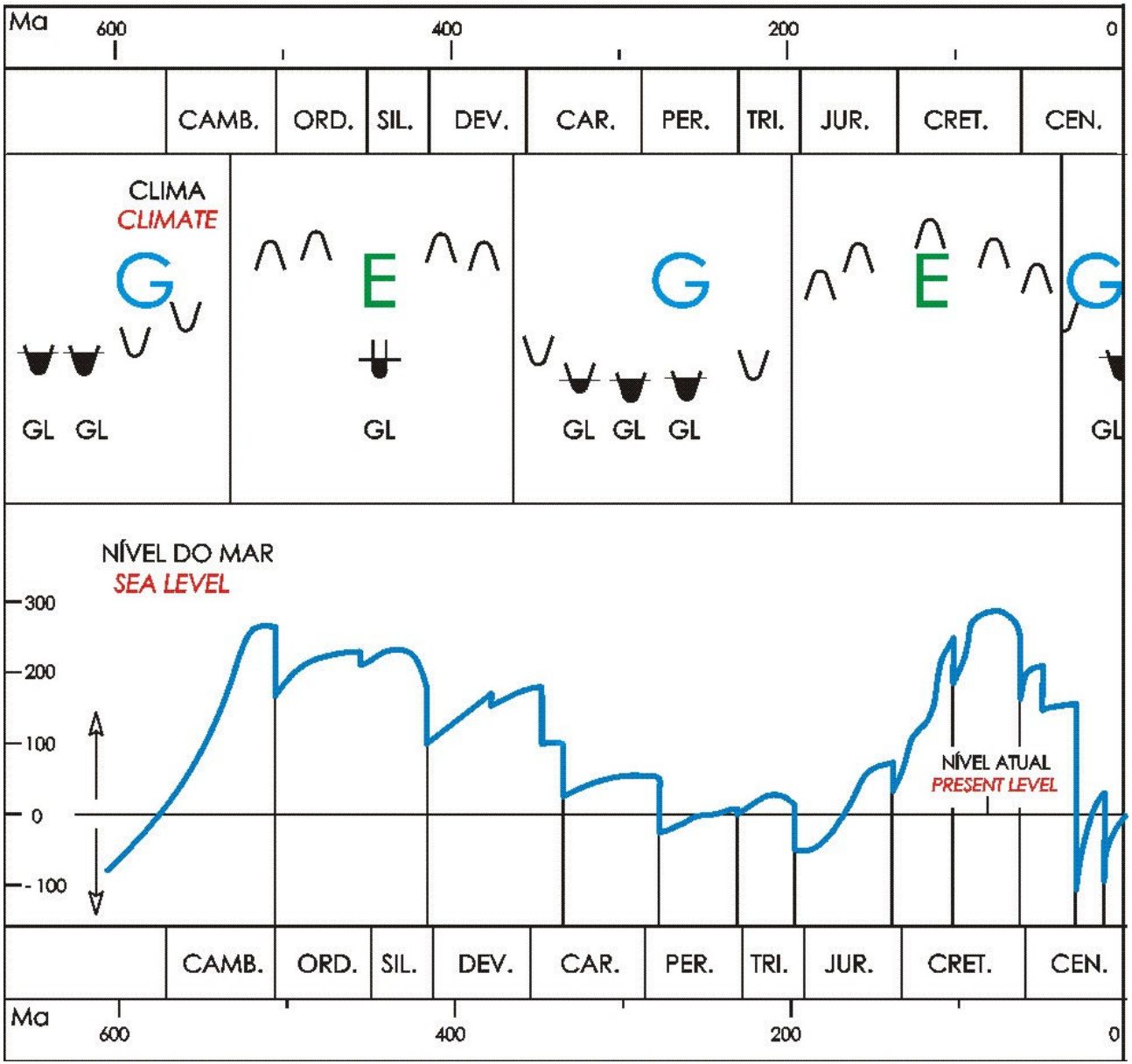
PHANEROZOIC EVOLUTION: SEDIMENTARY BASINS


80°W
60°W
40°W
0°
20°S
40°S
Andes
Pacific Ocean
Atlantic Ocean
Trópico Capricórnio
Romanche Chain
F. Noronha Chain
Vitória-Trindade Chain
TK
AM
SO
AC
AT
PC
PA
PR
PL
MA
SL
BA
PN
PO
AR
JA
TU
RE
PP
SA
CM
SF
ES
CA
SS
2000
4000
400 km
1. Basement
2. Andean Chain
3. Sineclise and Interior Basin
4. Rift Basin
5. Pre-Andean Basin
6. Marginal Basin

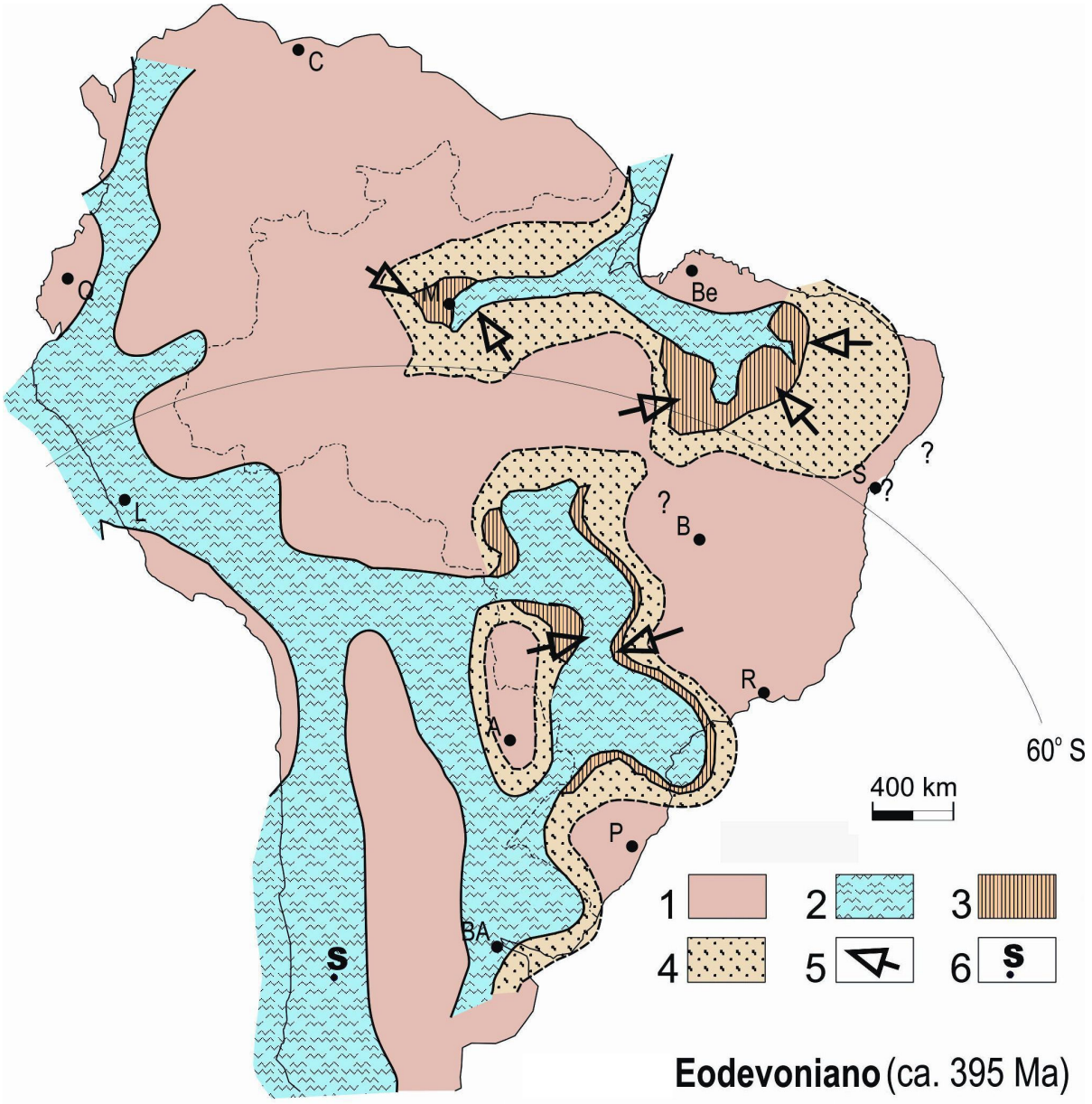
Sedimentary basins

Total thickness of accumulated materials

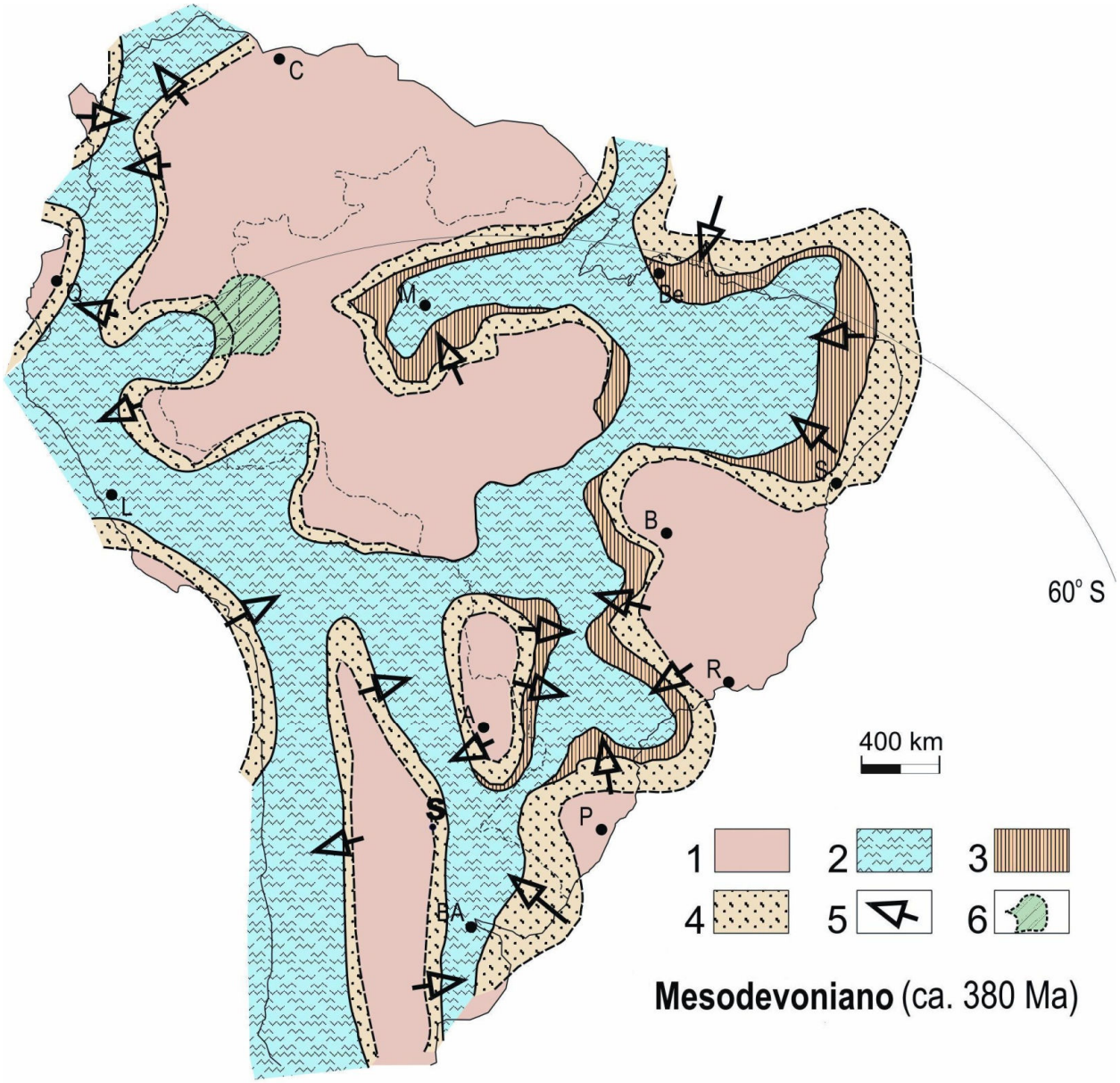



Ma
600
400
200
0
CAMB.
ORD.
SIL.
DEV.
CAR.
PER.
TRI.
JUR.
CRET.
CEN.
CLIMA
CLIMATE
G
E
G
E
G
GL GL
GL
GL GL GL
GL
NÍVEL DO MAR
SEA LEVEL
300
200
100
0
- 100
NÍVEL ATUAL
PRESENT LEVEL
CAMB.
ORD.
SIL.
DEV.
CAR.
PER.
TRI.
JUR.
CRET.
CEN.
Ma
600
400
200
0

Ancient seas...



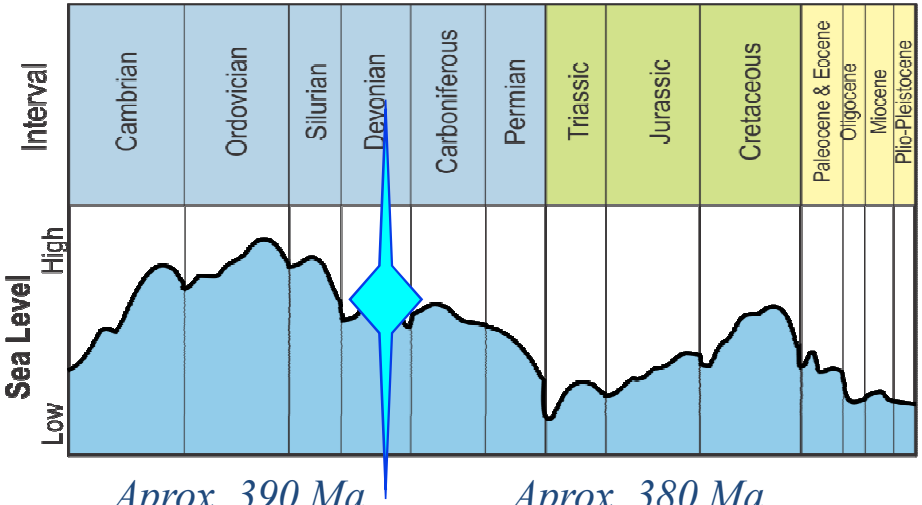
Almeida & Carneiro 2004



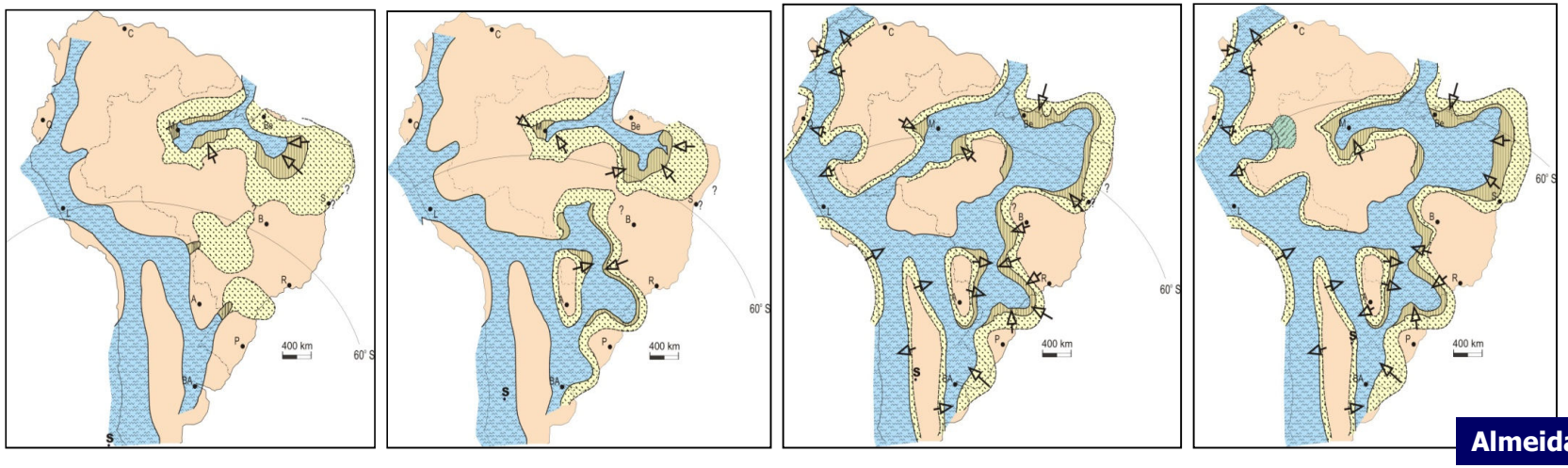
Almeida & Carneiro 2004

Devonian marine transgression

- Epicontinental seas covered ¼ of Brazil
  - Modified from Melo (1989)



Aprox. 400 Ma *Aprox. 395 Ma* *Aprox. 390 Ma* *Aprox. 380 Ma*

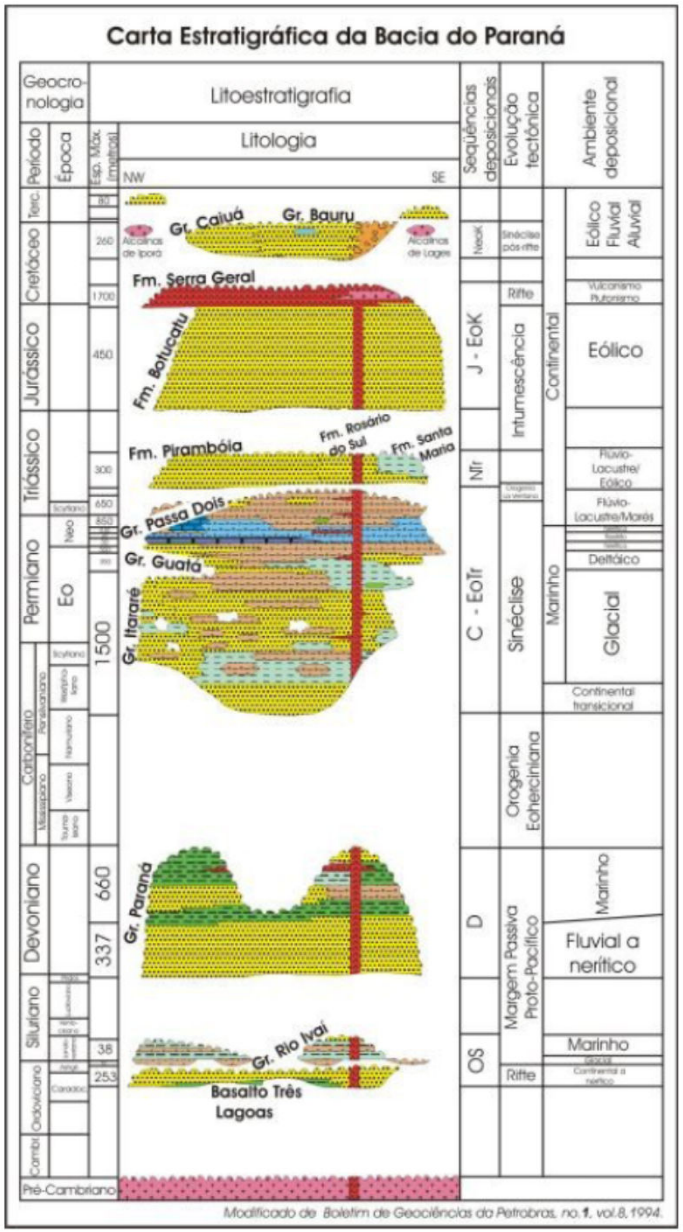


Almeida & Carneiro 2004

Supersequences

Paraná Basin

- **Bauru**
- **Gondwana III**
  - Sandstones / conglomerates
    - Sand desert and basalt flows (South-Atlantic rift)
- **Gondwana II**
- **Gondwana I**
  - Marine siltstones and shales / continental sandstones
    - Glaciation
- **Paraná**
  - Shales and marine sandstones
- **Rio Ivaí**



Varvite beds, Itu, SP

Athabasca Glacier, Jasper National Park, Canada

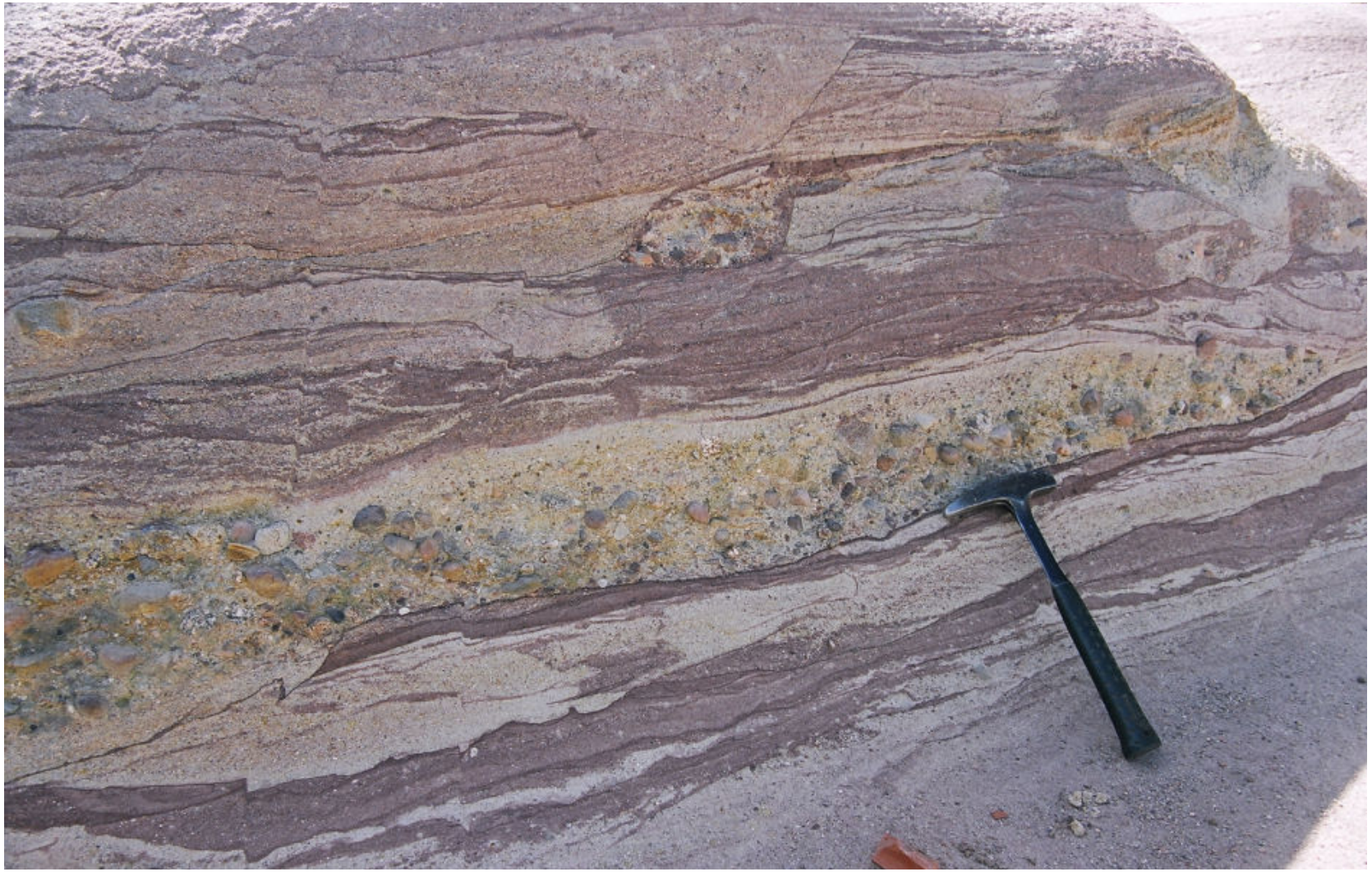
Altitude: 2,700 m
Area: 6 km^2
Mean thickness: 300 m
Velocity: 125 m/yr (top) X 25 m/yr (base)

Peyto Lake

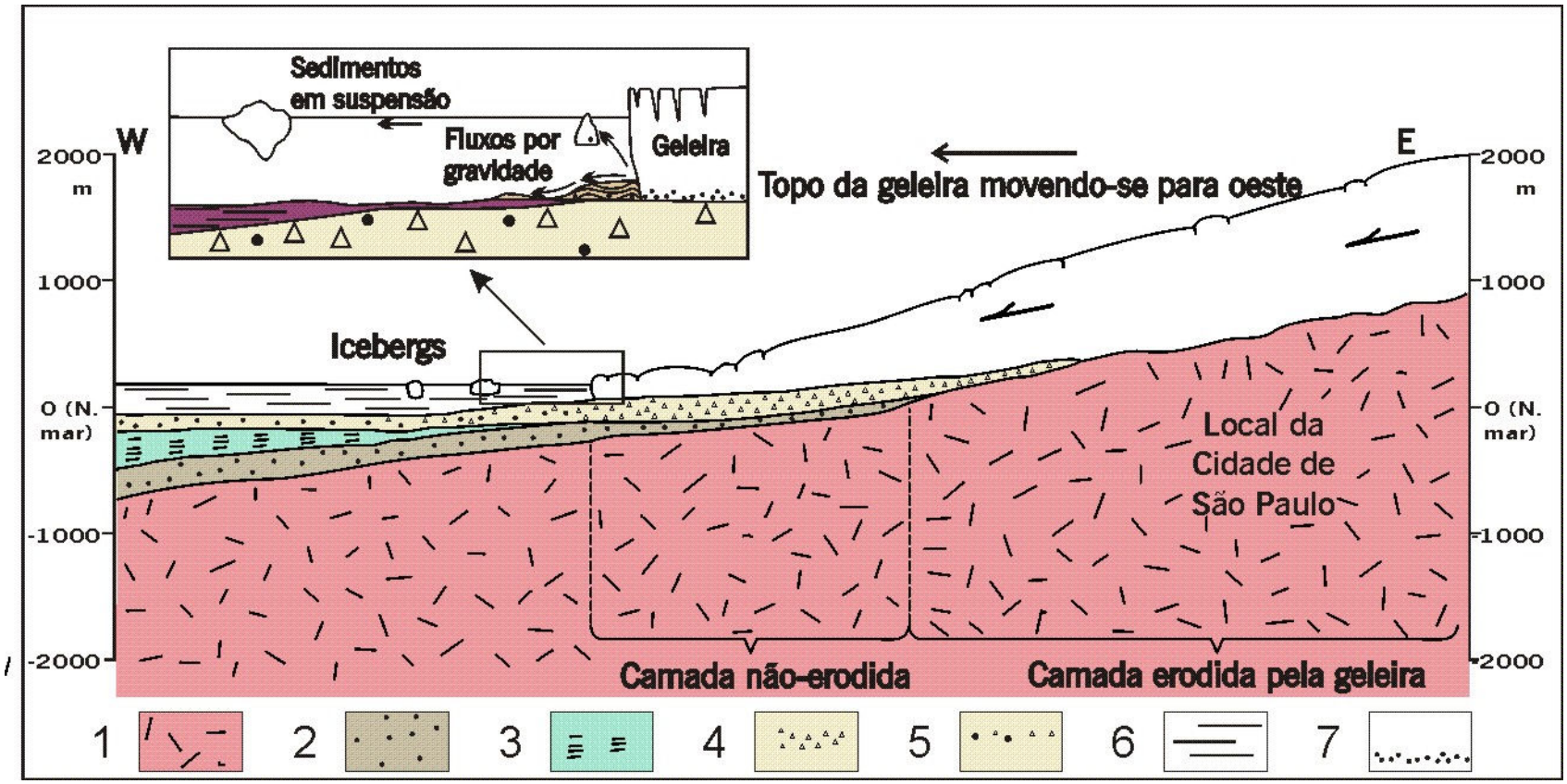
Peyto Lake: flow of sediments from glacier

P-C sandstone beds, Campinas (SP)

Itararé Group: sandstones and conglomerates



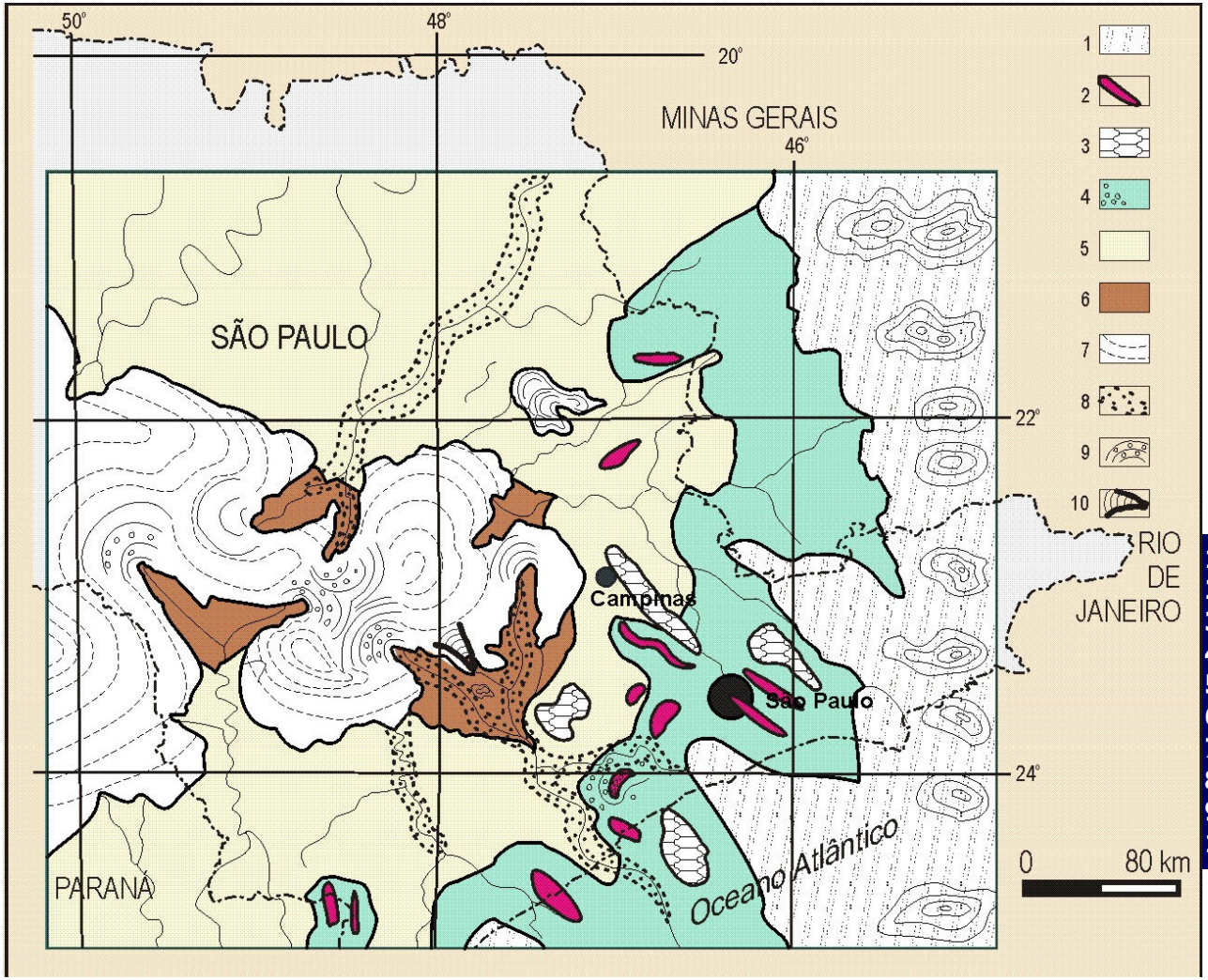
A Permian-Carboniferous glacier



Hypothetic profiles: 1 - Basement; 2 – Furnas Sandstone; 3 – Ponta Grossa Shale; 4 – glacial sandstone; 5 – Till; 6 – Pellites; 7 – Icebergs transporting pebbles

Washburne (1930); box from Vesely & Assine (2004)

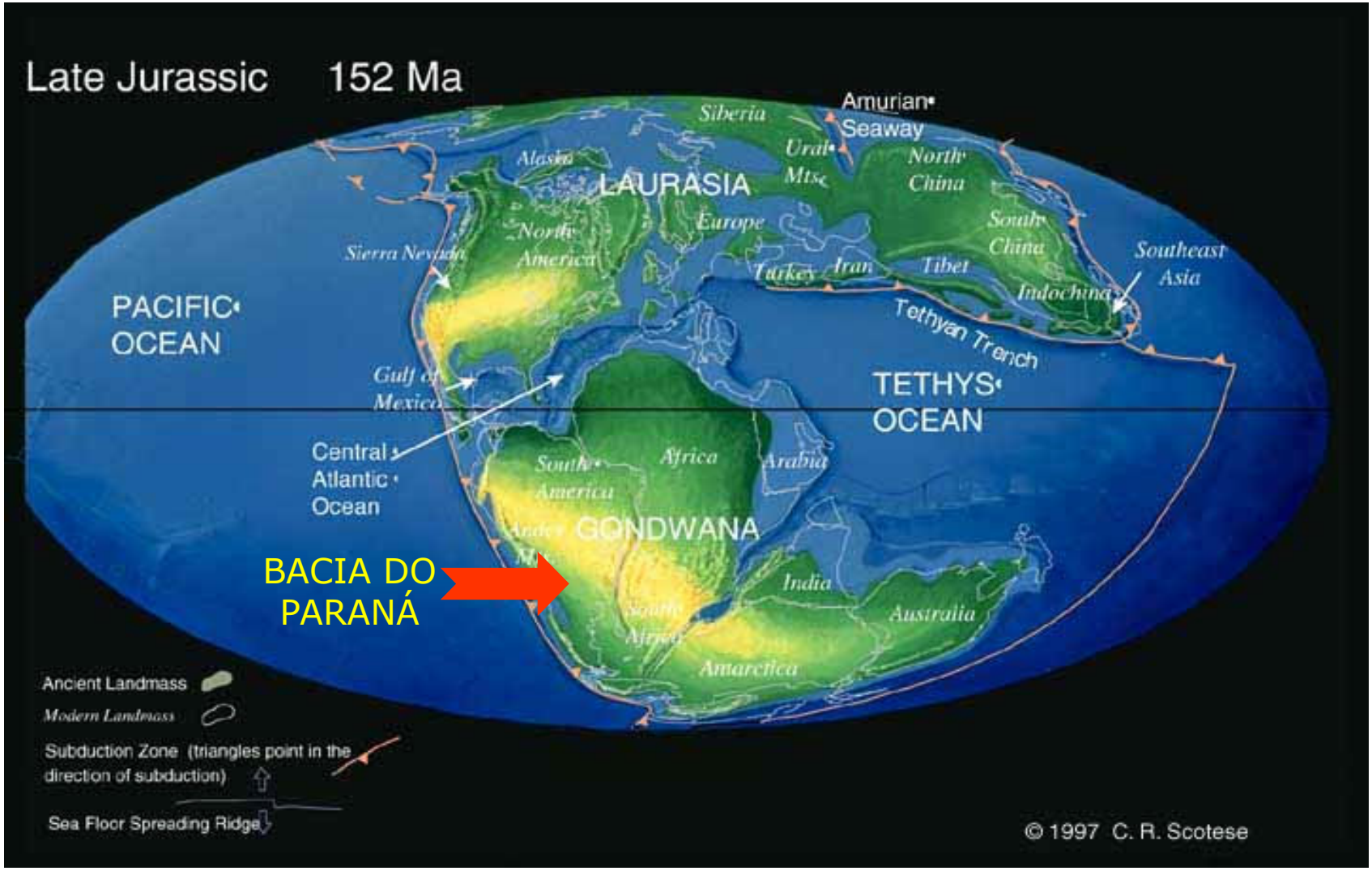
Permian-Carboniferous Glaciation



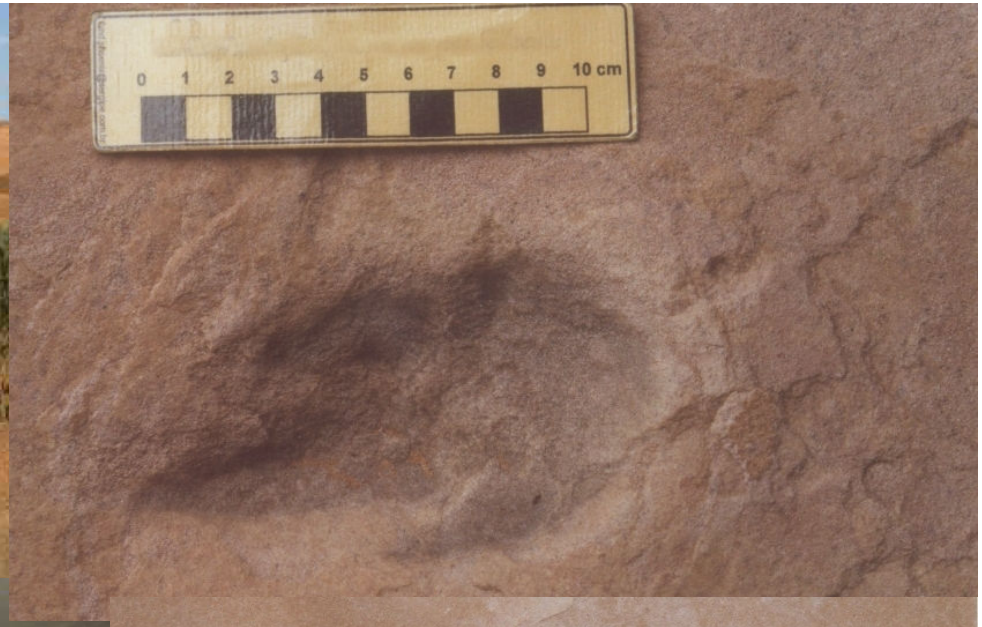
1 Glaciers
2 Drumlins, eskers
3 Peri-glacial lakes
4 Outwash
5 Aluvial plan
6 Deltaic plan
7 Deltaic Platform
8 Fluvial channels, sand / pebbles
9 Sediment slides on deltaic fronts
10 Sand flows

Soares et al. (1977)

Botucatu Paleodesert



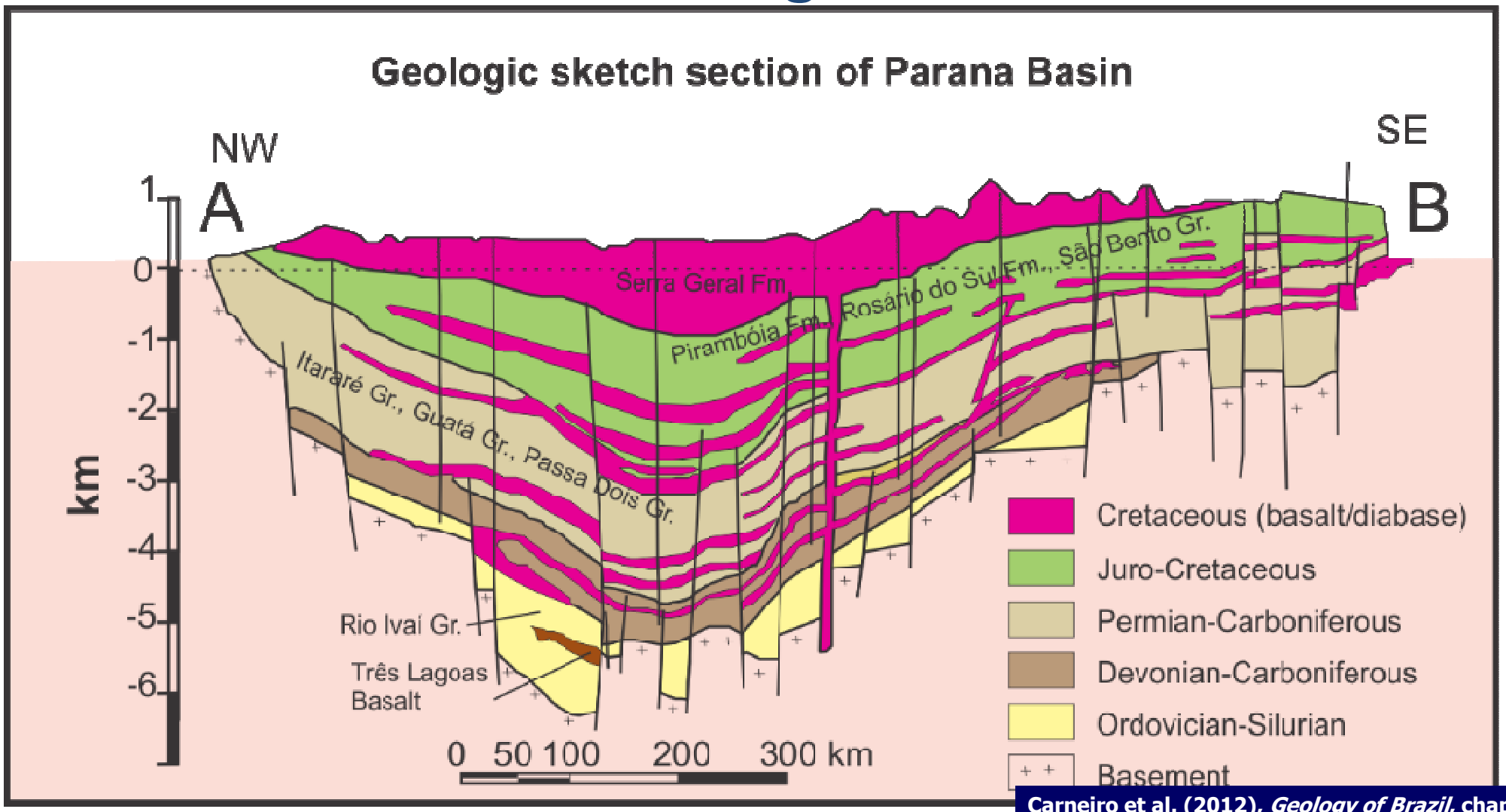
Oasis, Marrocos



Sands, Sahara Desert

Dinosaur footprints, Botucatu (SP)

Serra Geral lavas covering Botucatu sandstones



Carneiro et al. (2012), *Geology of Brazil*, chapt. 16

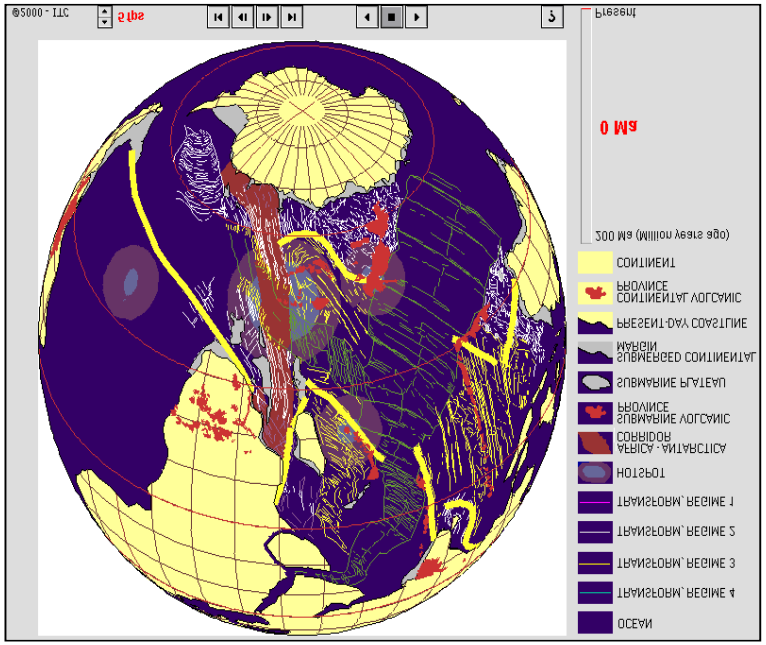
Geology & relief of South America

BREAK-UP OF GONDWANA

Volcanism covering deserts...

Art: Wladimir Parrilo

Animation Gondwana.exe

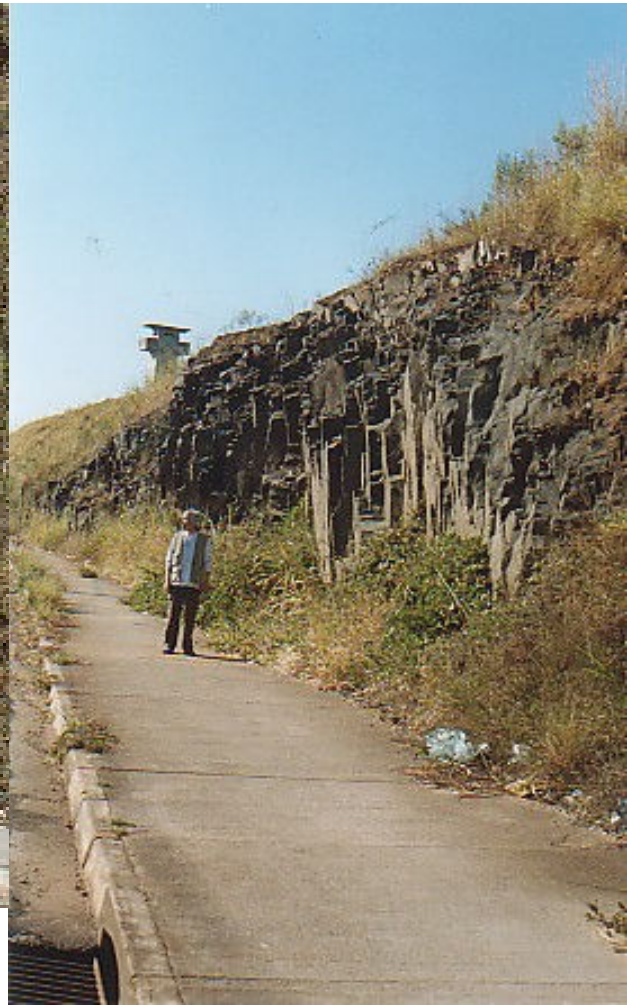


Source: http://www.geophysik.tu-freiberg.de/~spitzer/download/vorlesungen/Grundlagen_der_Geophysik/gondwana.exe

Basalt flows (Lower Cretaceous)

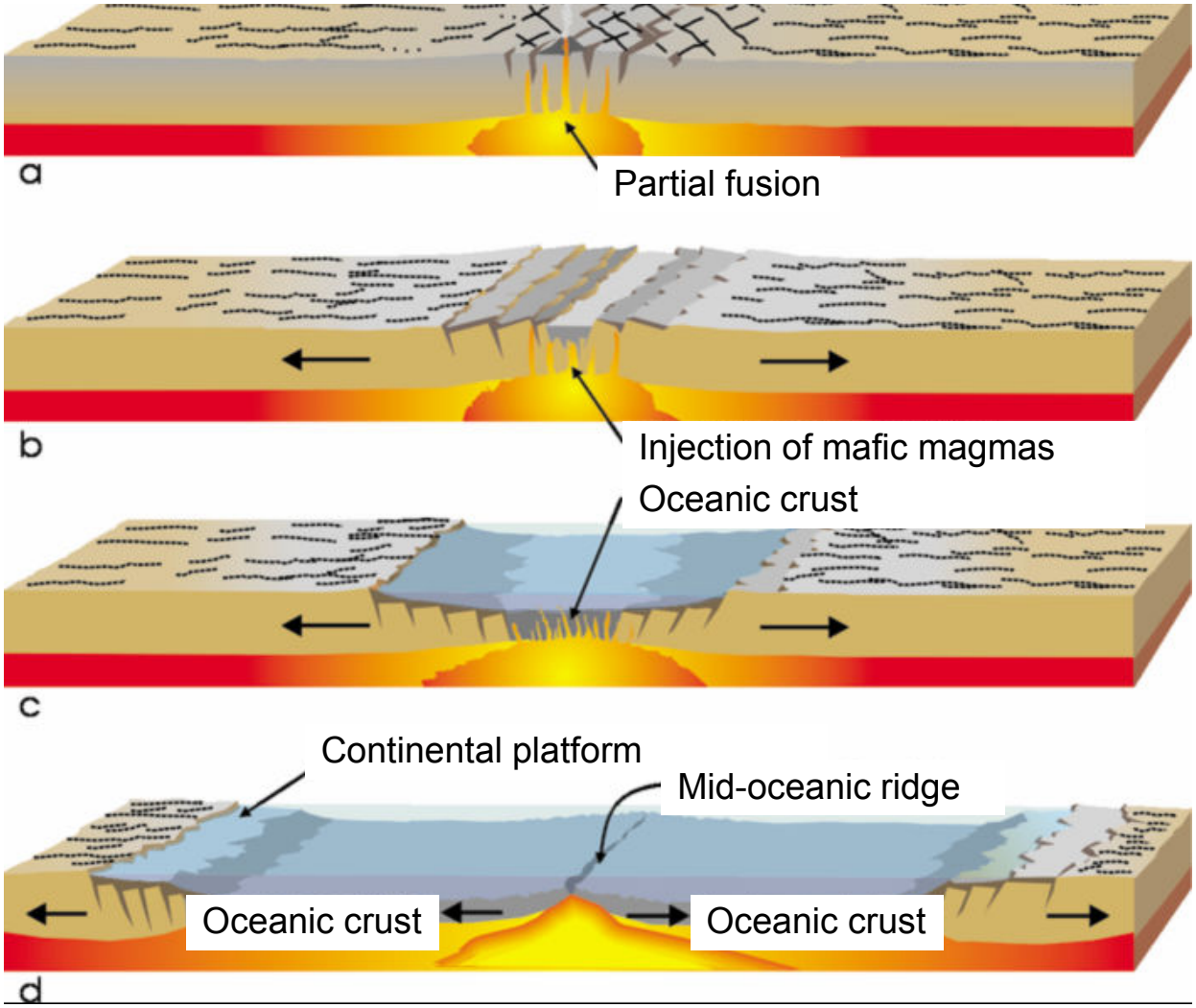
http://www.skyscrapercity.com/showthread.php?p=30696266

“Terra Roxa”: weathering of basalt / diabase

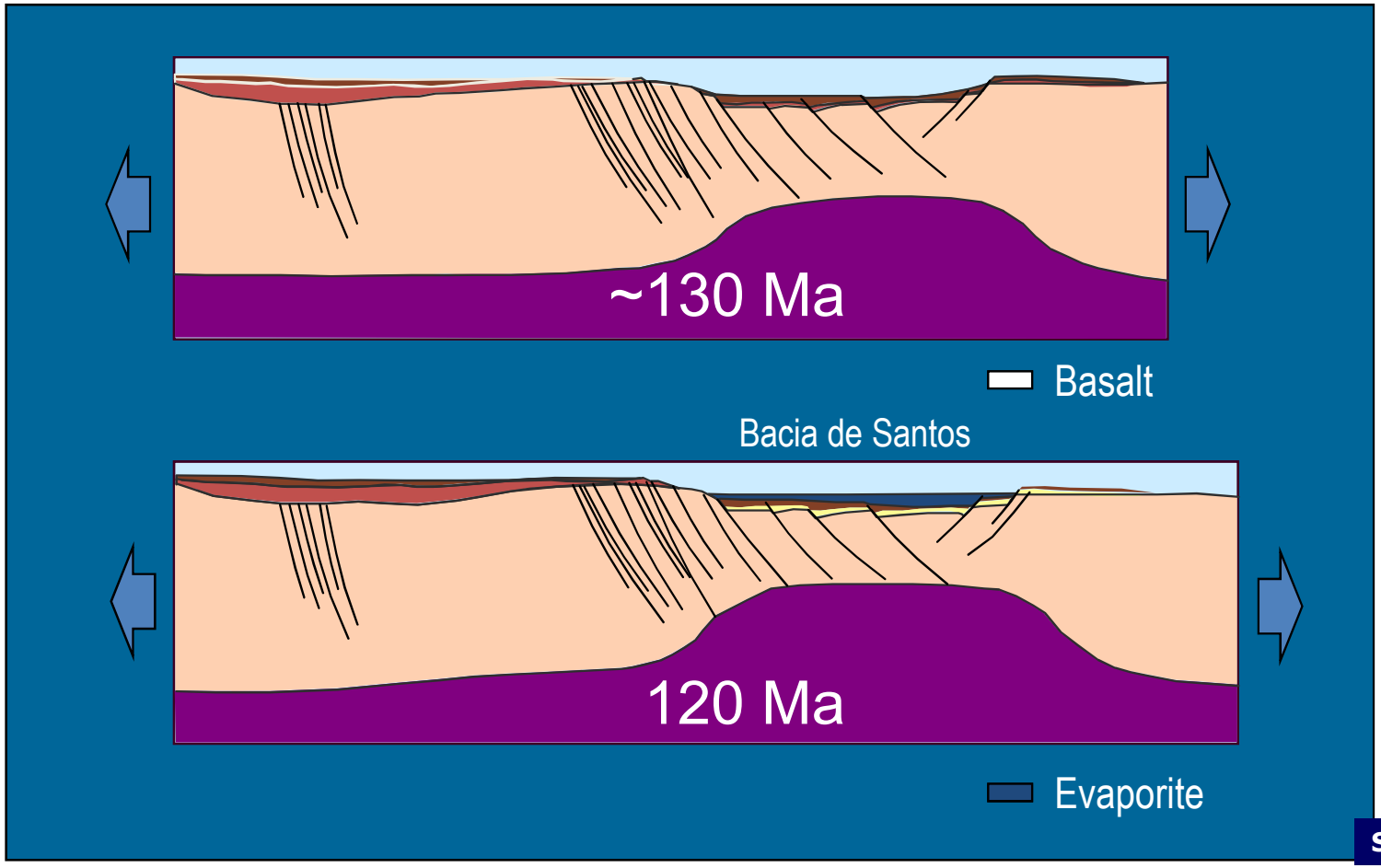


http://www.codem.org.br/investe/

Phases of Gondwana break-up



Thinning stage of the crust

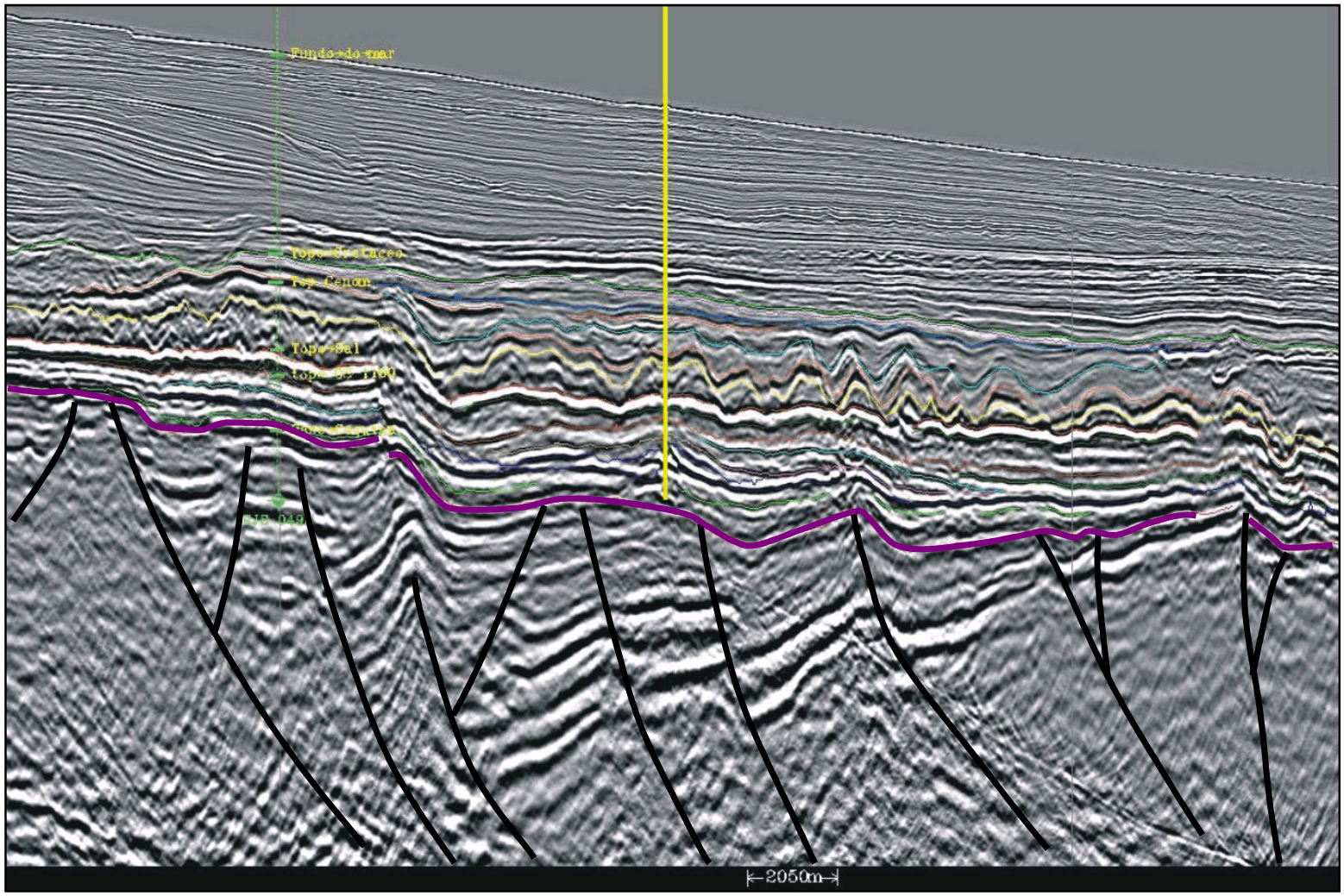


Source: Macedo (1991)

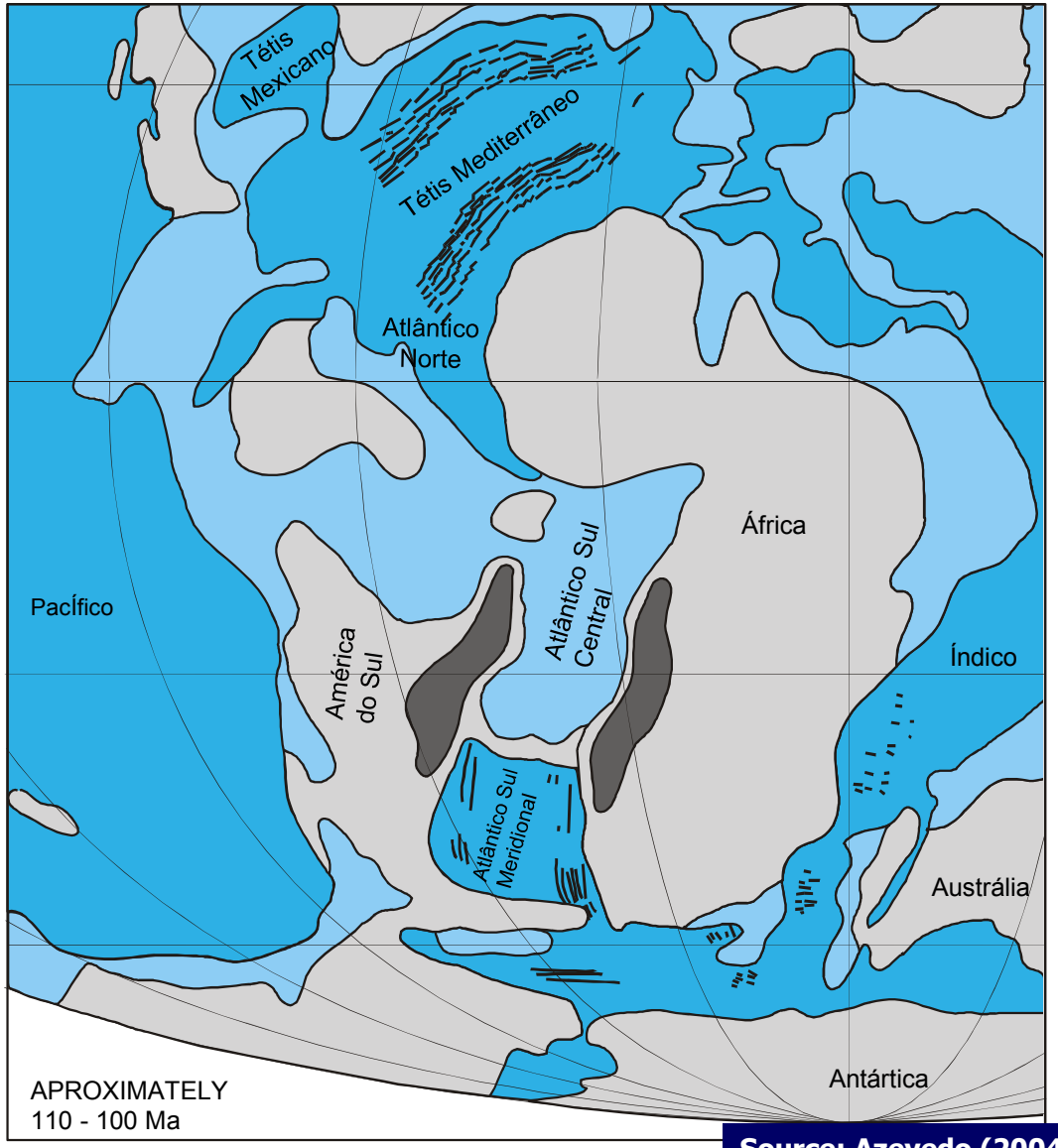
Lacustrine sediments of Recôncavo Graben

Image credit: Pedro Victor Zalán

Pre-salt rifts of Campos Basin

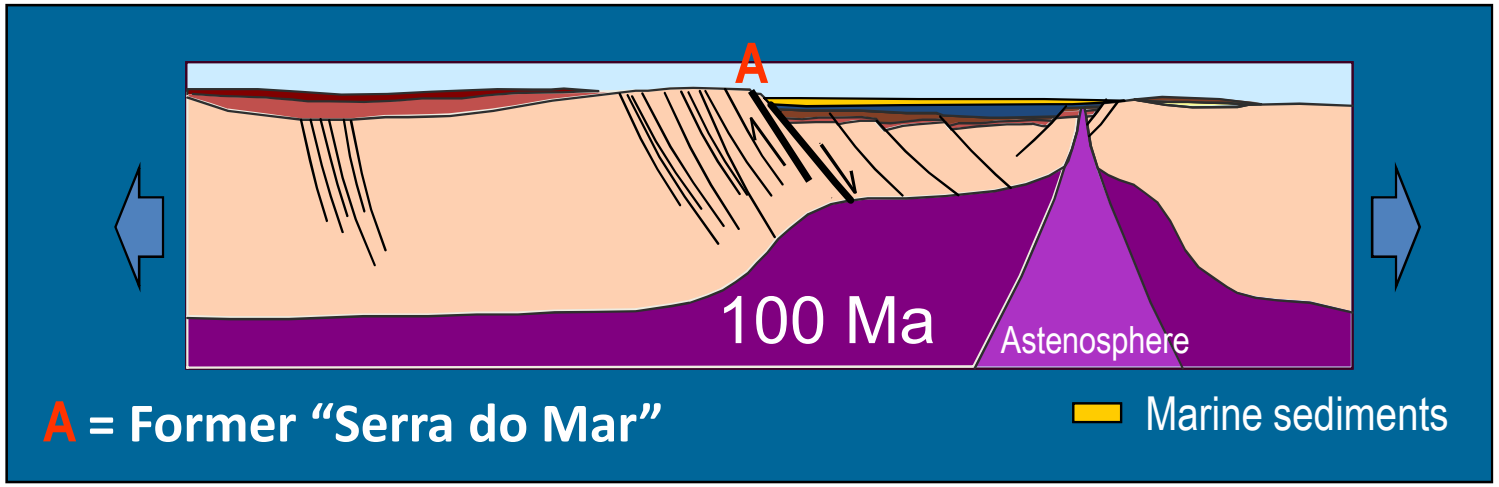


Paleogeographic reconstruction of South Atlantic and adjoining seas during the Albian

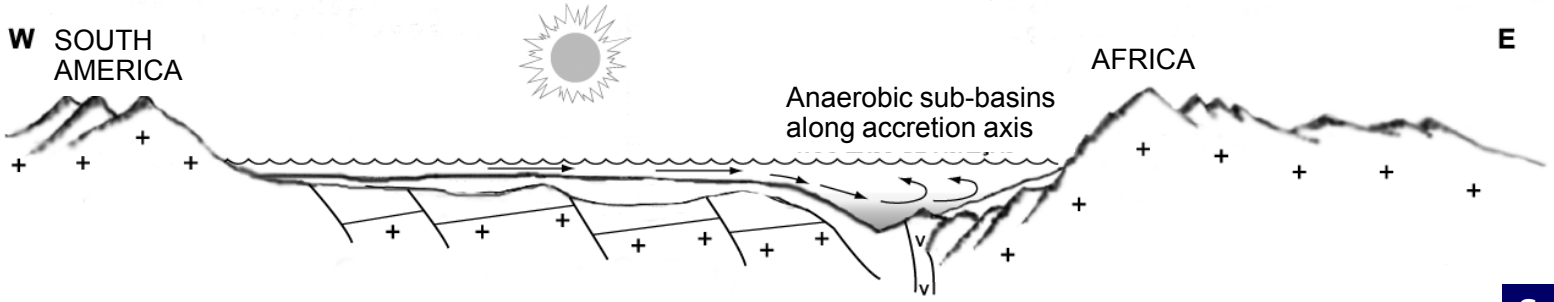


Source: Azevedo (2004)

Forming the first oceanic floor

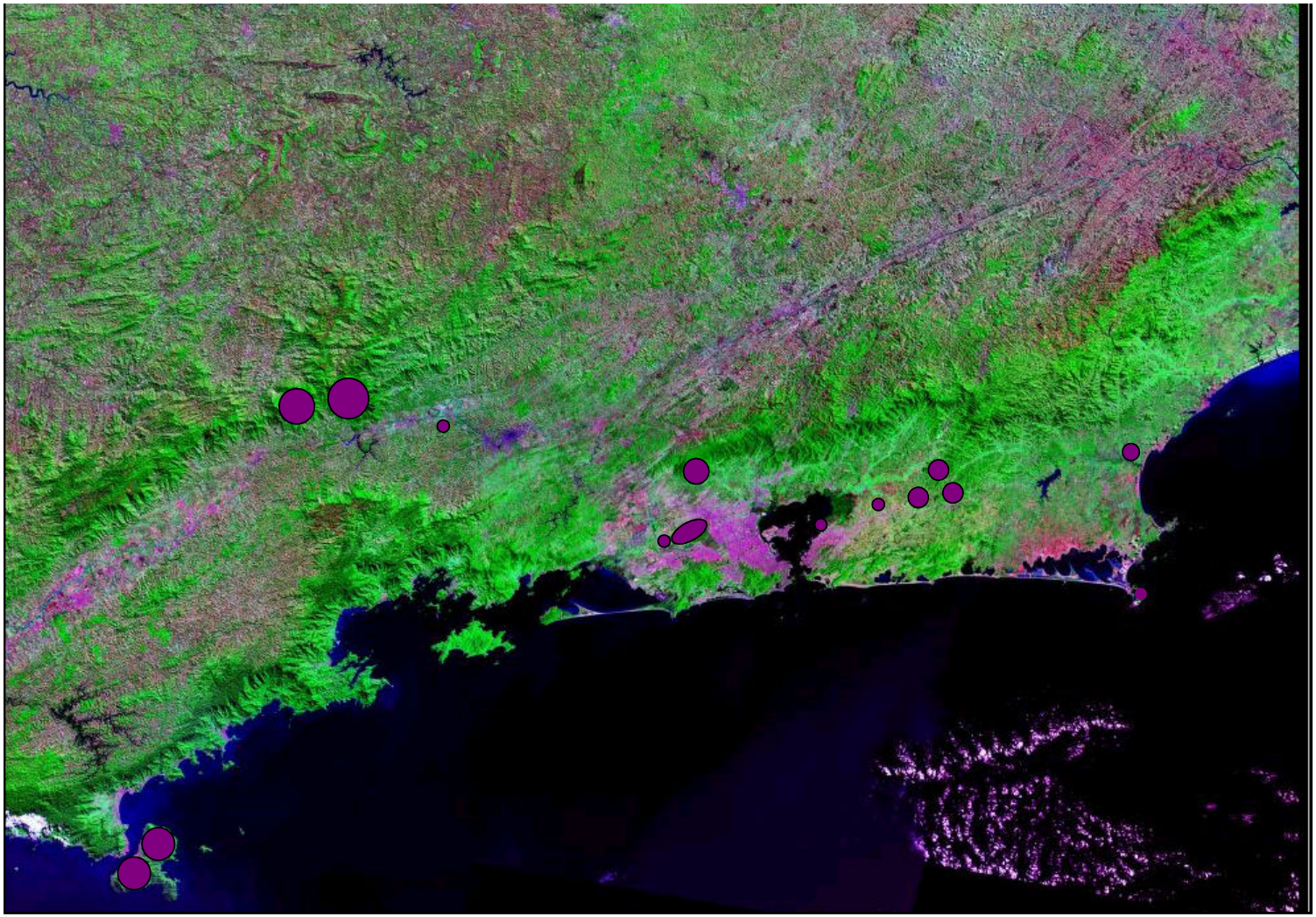


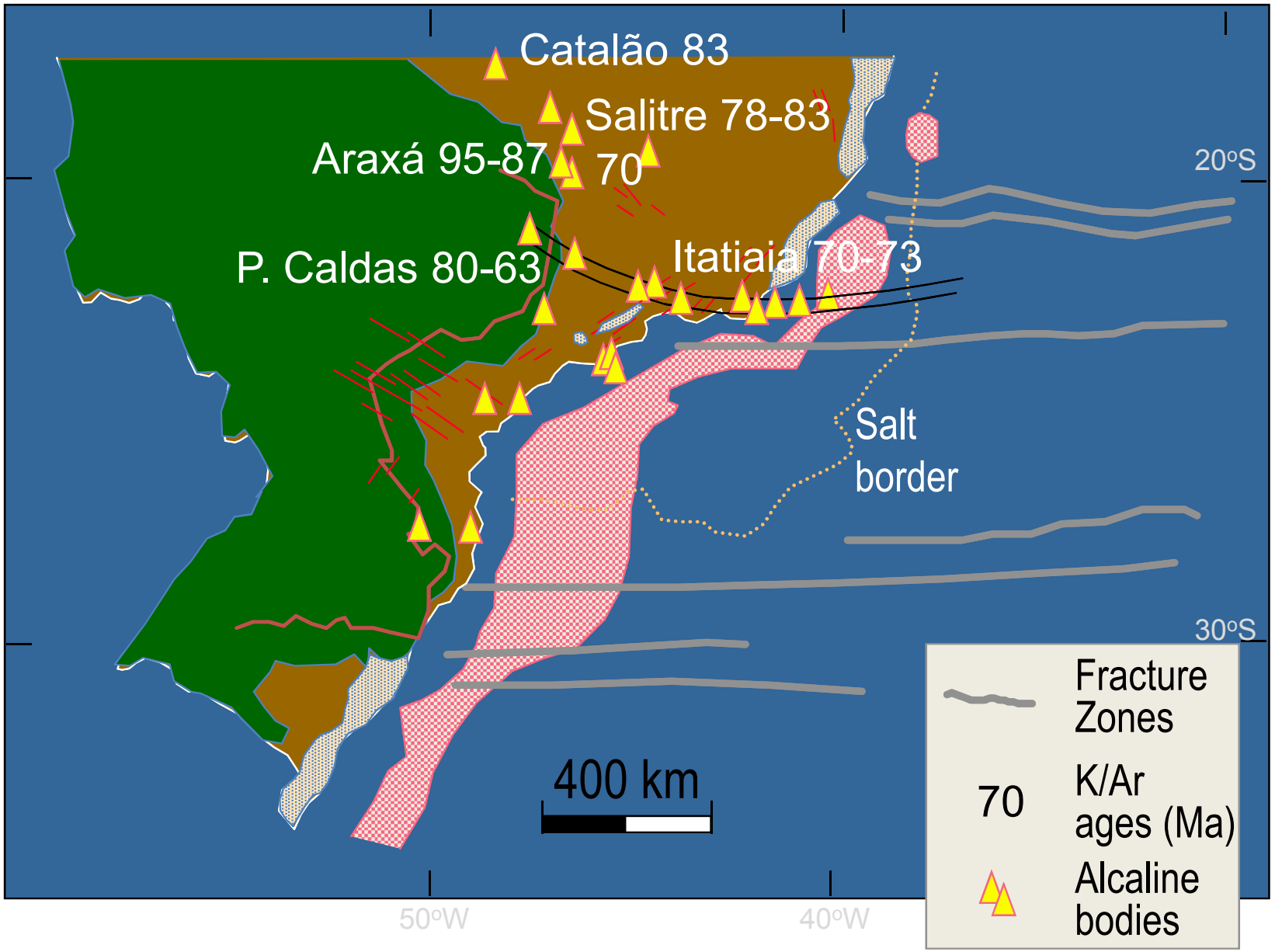
Transversal profile of Central South Atlantic



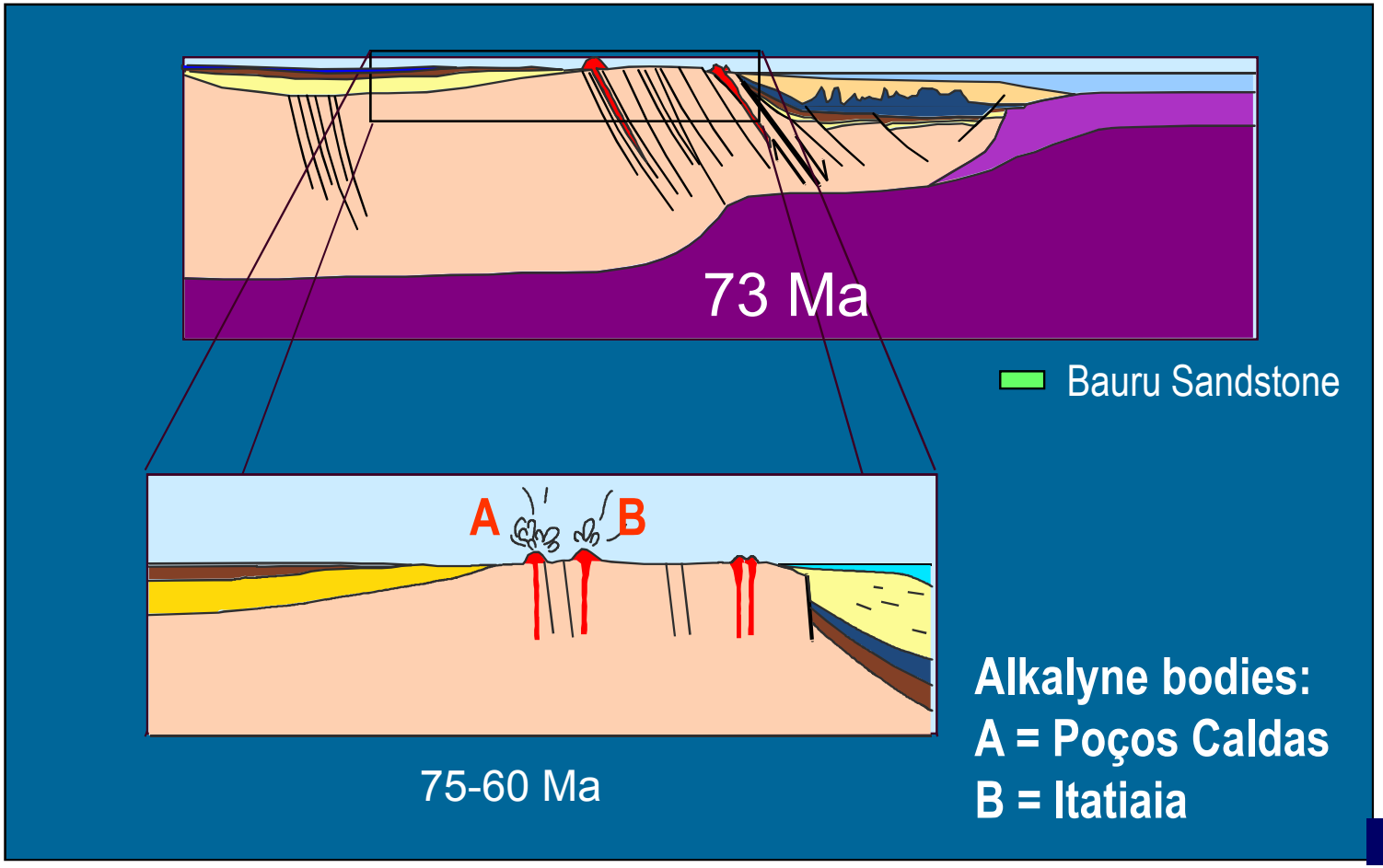
Source: Macedo (1991)

Alkaline intrusions: Upper Cretaceous / Paleogene



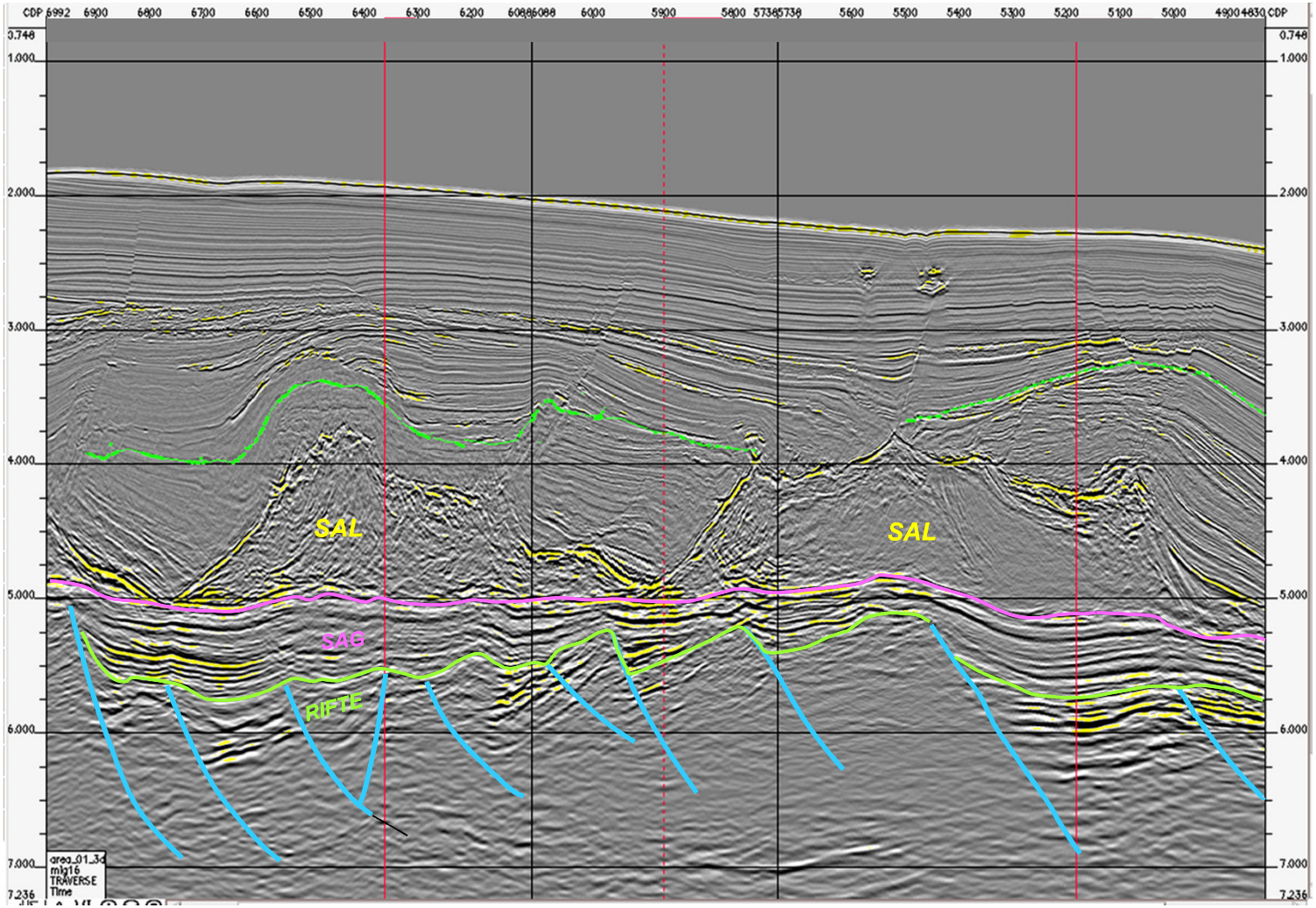

Catalão 83
Salitre 78-83
Araxá 95-87
70
P. Caldas 80-63
Itatiaia 70-73
Salt
border
20°S
30°S
50°W
40°W
400 km
Fracture
Zones
70
K/Ar
ages (Ma)
Alcaline
bodies

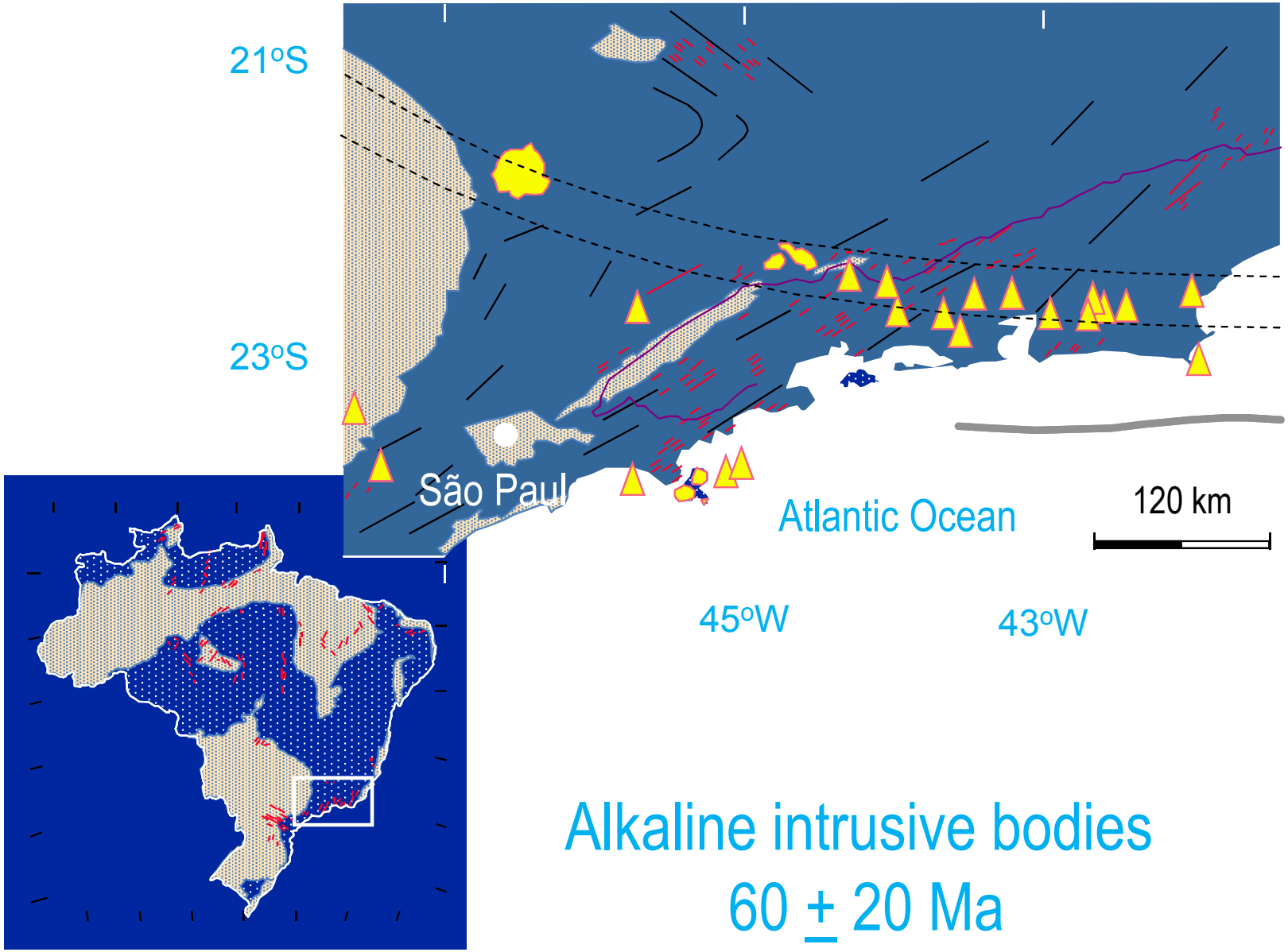
Sea-floor spreading



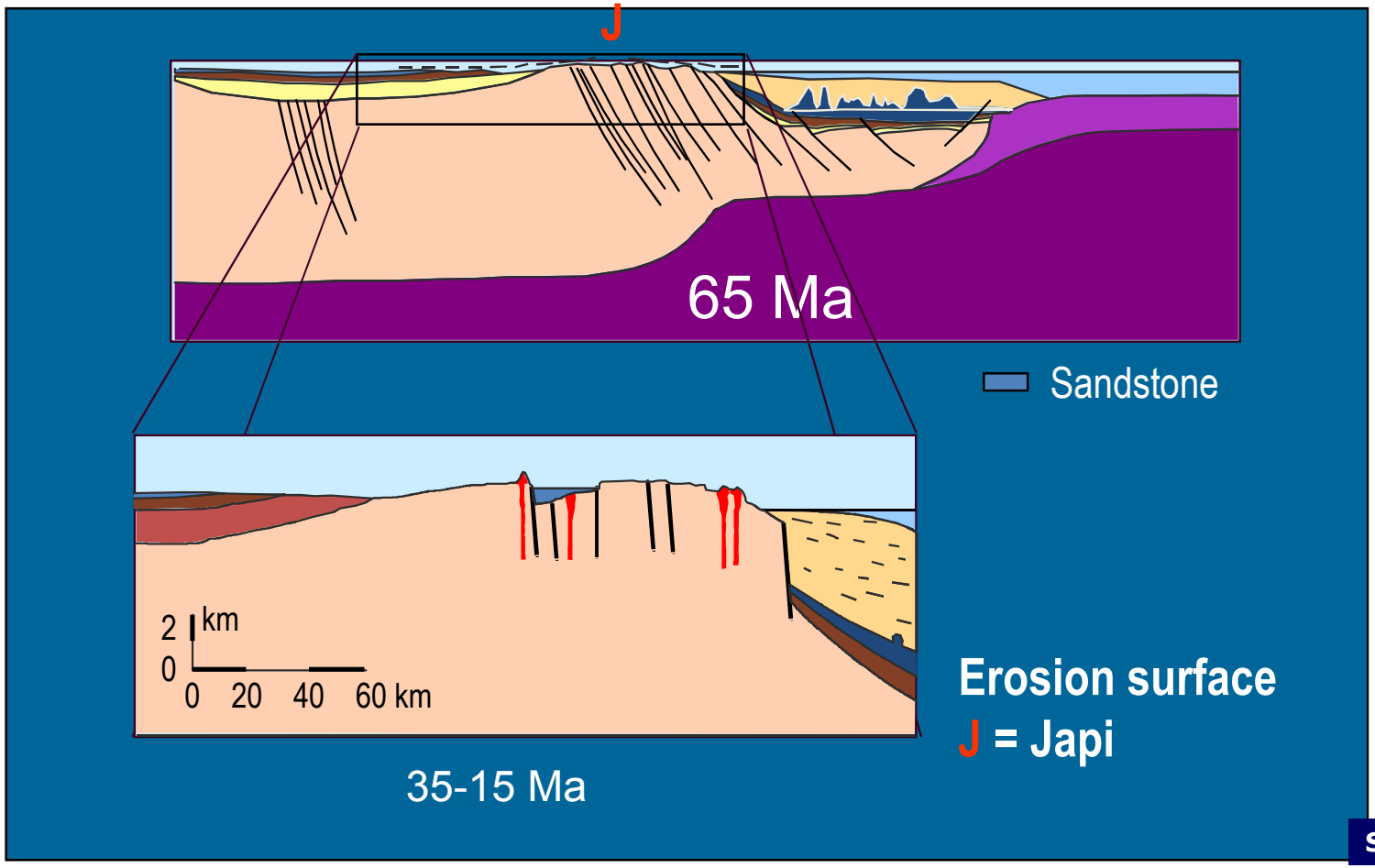
Source: Macedo (1991)

Pre-salt rifts of Santos Basin




21ºS
23ºS
São Paul
Atlantic Ocean
120 km
45ºW
43ºW
Alkaline intrusive bodies
60 ± 20 Ma

Japi Surface and uplift of the continental margin

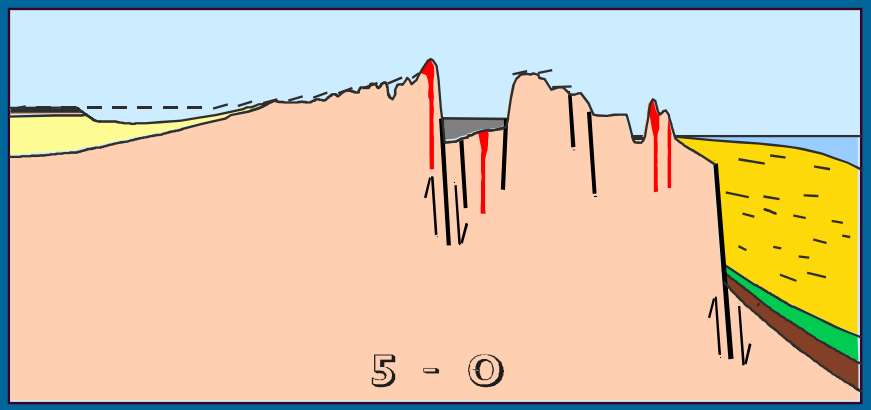


Source: Macedo (1991)

Continental margin uplift

Tectonic subsidence of blocks and preservation of sedimentary covers

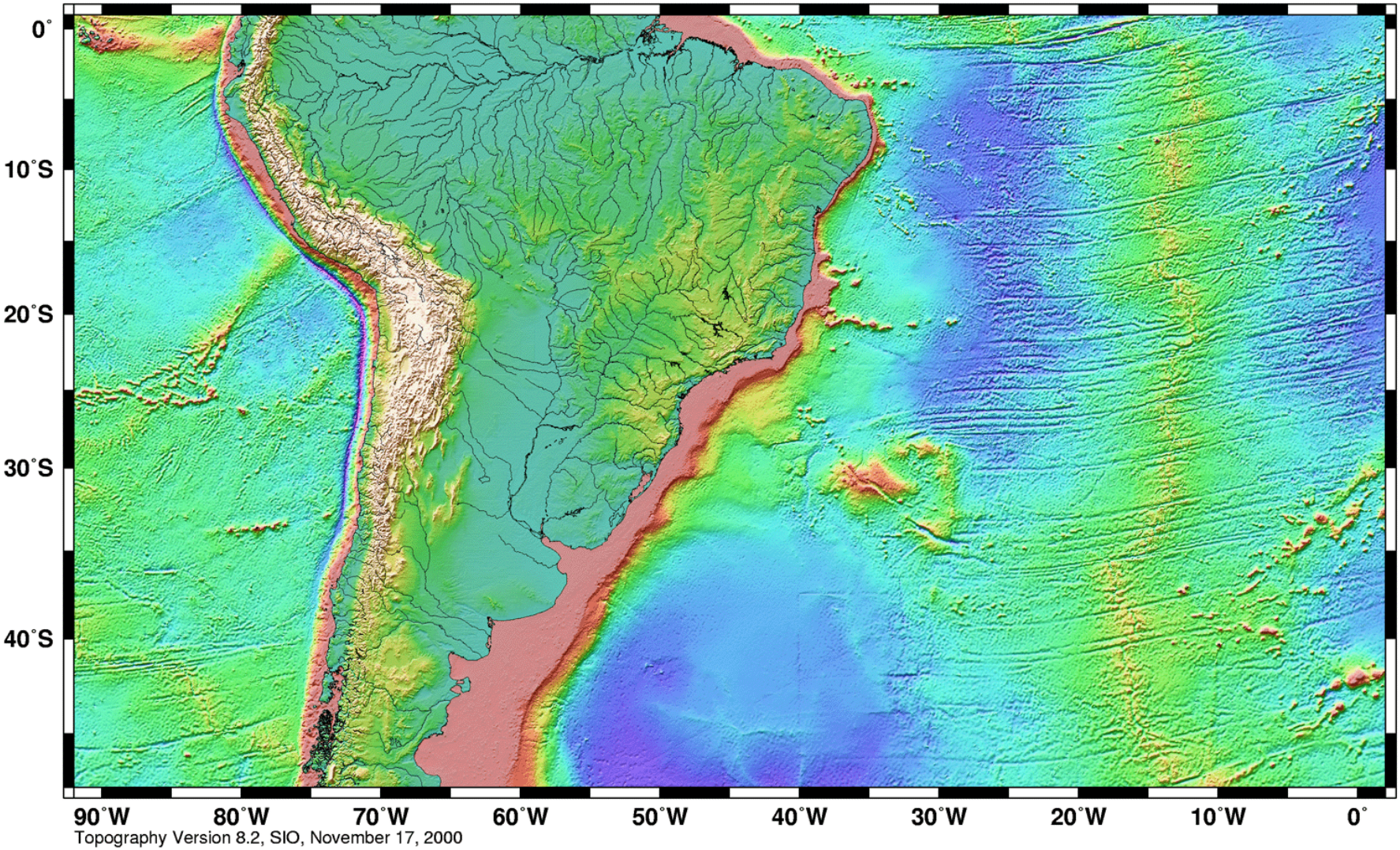
Paraná Basin | Taubaté Basin | Santos Basin



5-0 Ma

Great vertical exaggeration

Source: Macedo (1991)



http://topex.ucsd.edu/marine_topo/gif_topo_track/topo12.gif

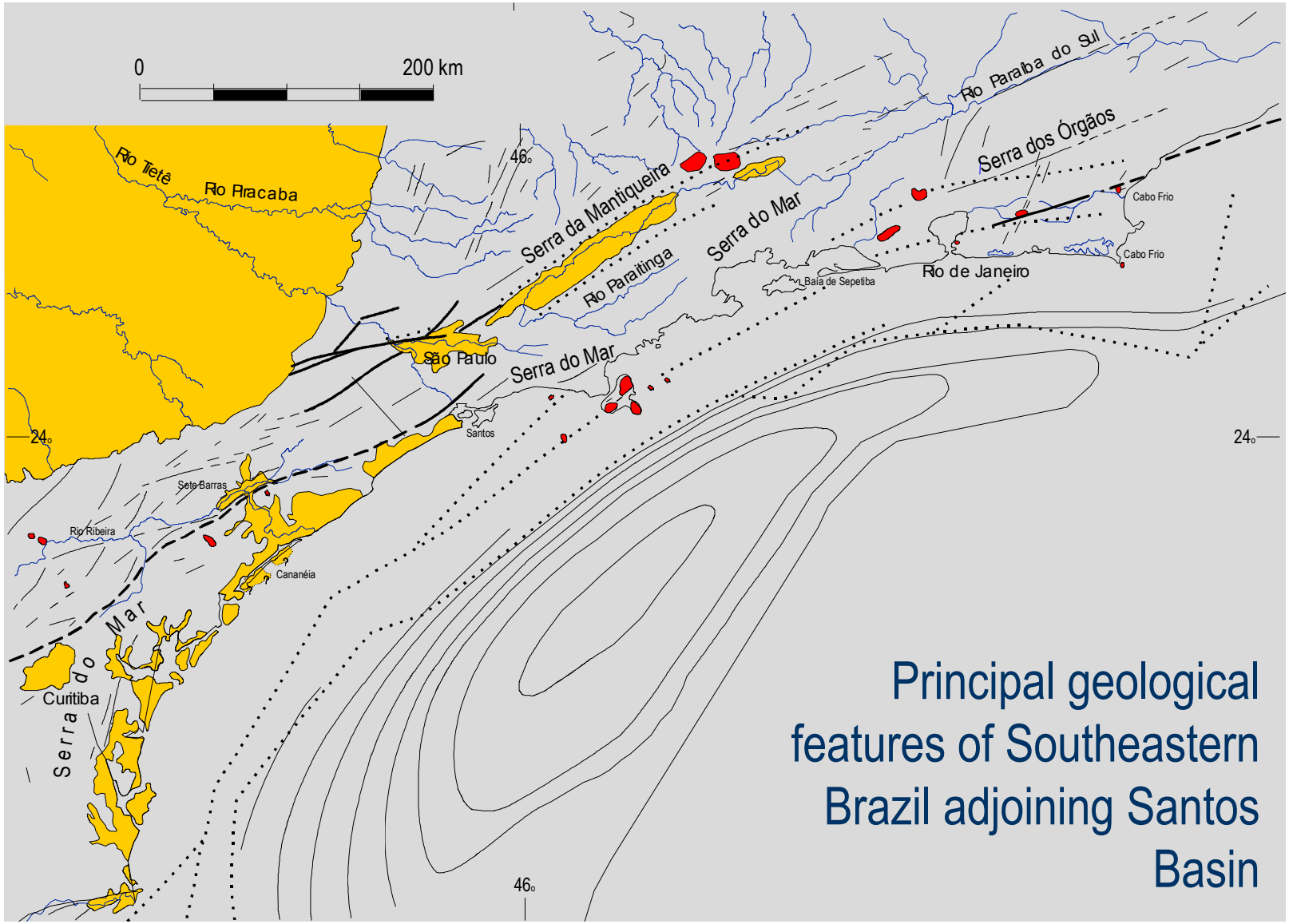
VIII GeoSciEd 2018 – 8th Quadrennial Conference of the International Geoscience Education Organisation (IGEO)
– *Geosciences for Everyone* –
VIII Simpósio Nacional de Ensino e História de Ciências da Terra / EnsinoGEO-2018
– Geociências para Todos –
Campinas – Sao Paulo – Brazil, July 2018

Regional relief

The structure of the landscape

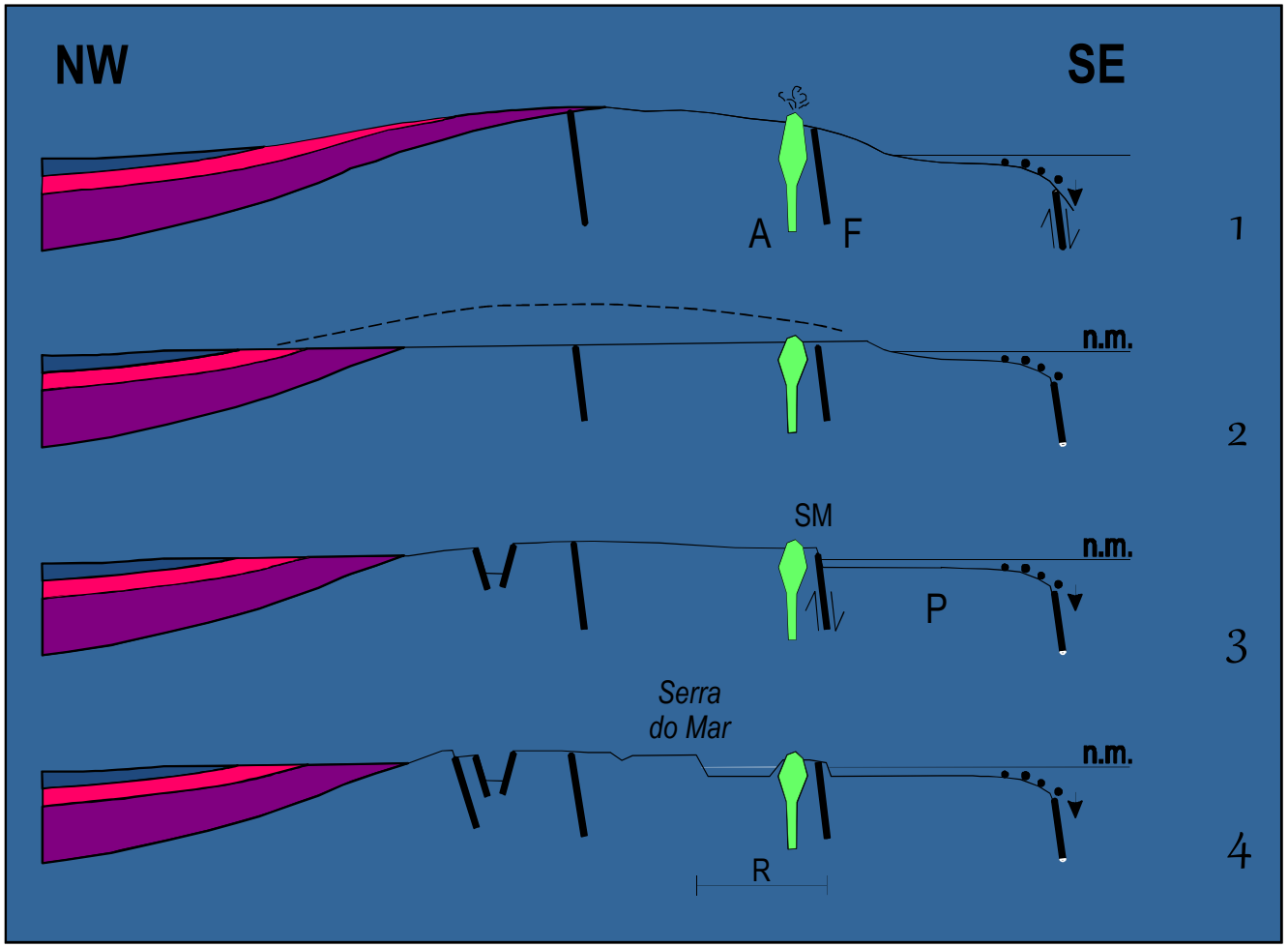
Sugar Loaf relief type (RJ)

http://tudoeturismo.com.br/wp-content/uploads/...1280x.jpg



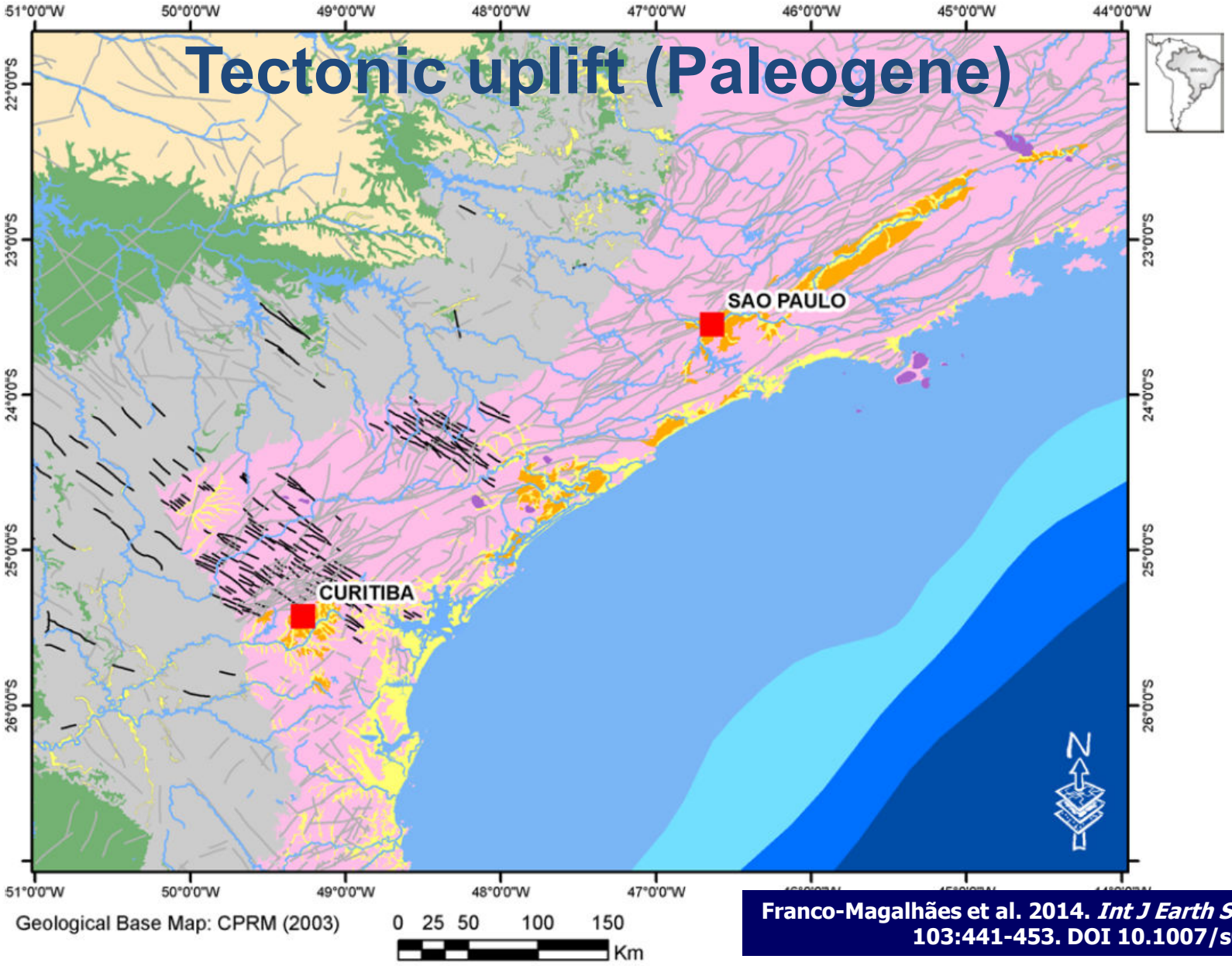
Principal geological features of Southeastern Brazil adjoining Santos Basin

What is the origin of Serra do Mar?



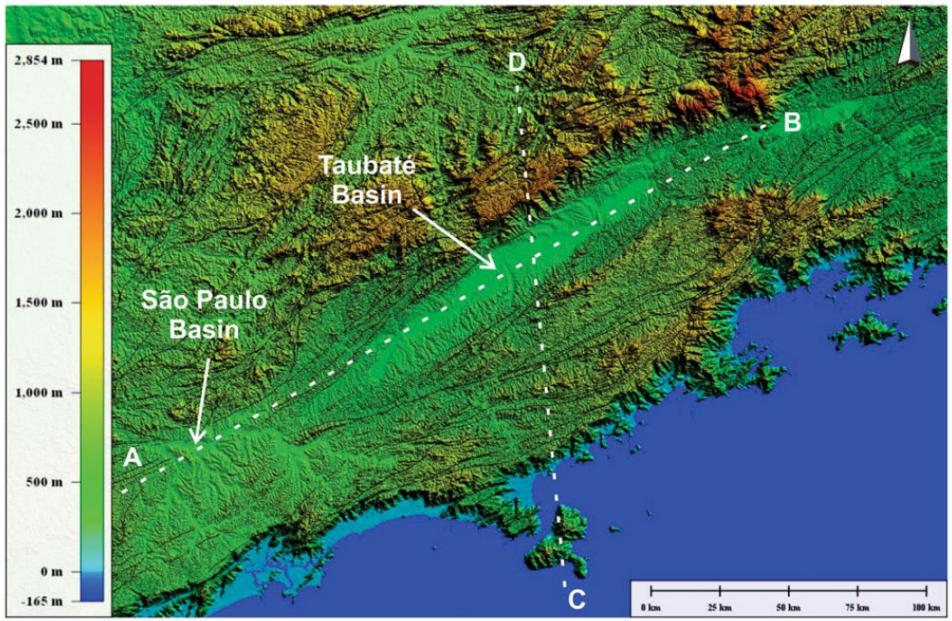
Almeida 1976

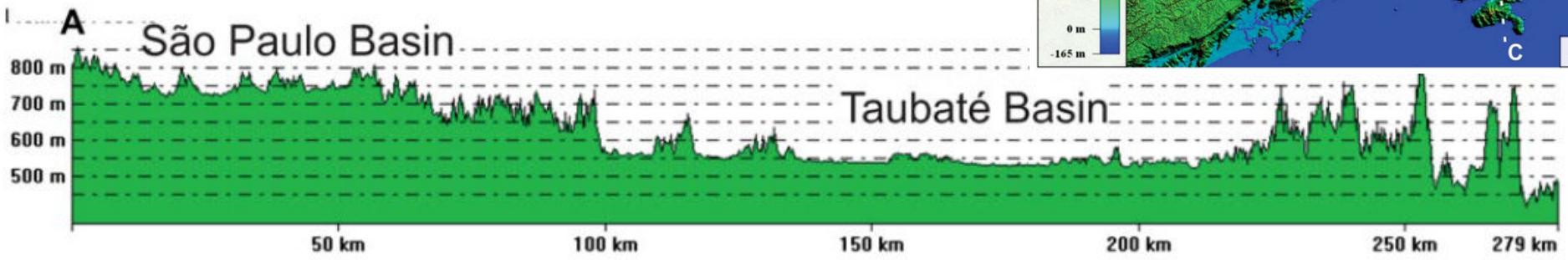
Tectonic uplift (Paleogene)

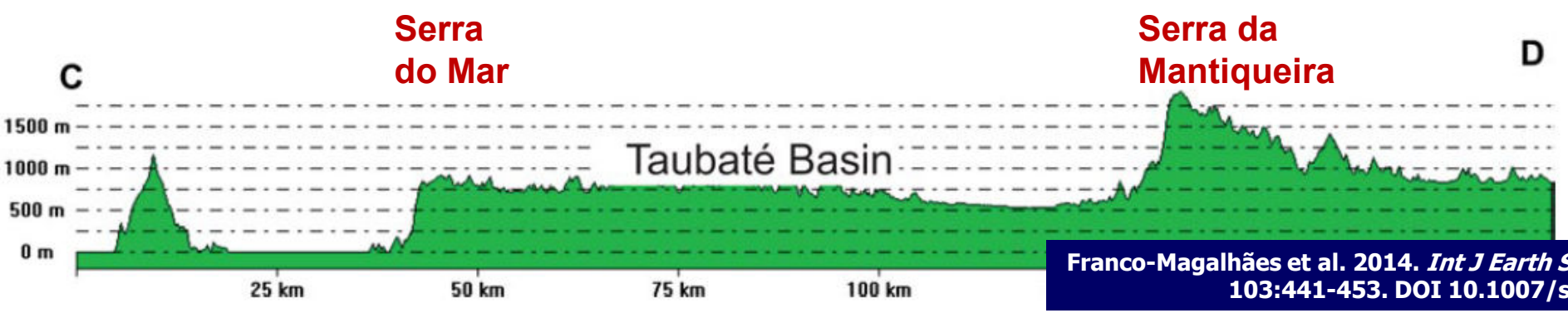


Franco-Magalhães et al. 2014. *Int J Earth Sci (Geol Rundsch)*, 103:441-453. DOI 10.1007/s00531-013-0967-4

Tectonic uplift (Neogene)







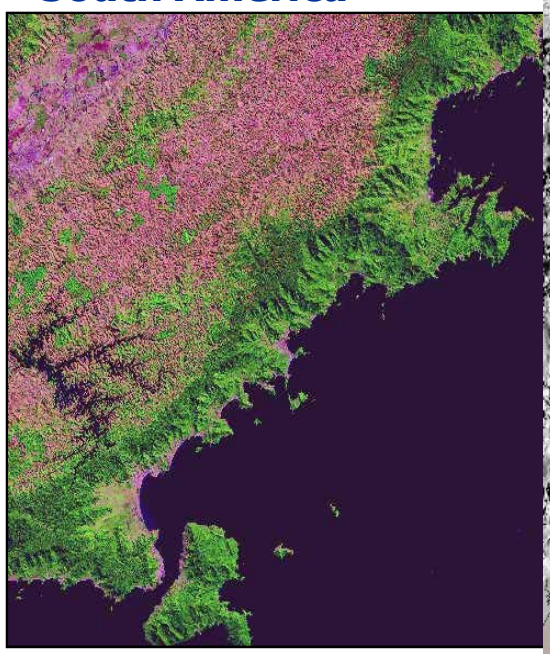
Franco-Magalhães et al. 2014. *Int J Earth Sci (Geol Rundsch)*, 103:441-453. DOI 10.1007/s00531-013-0967-4

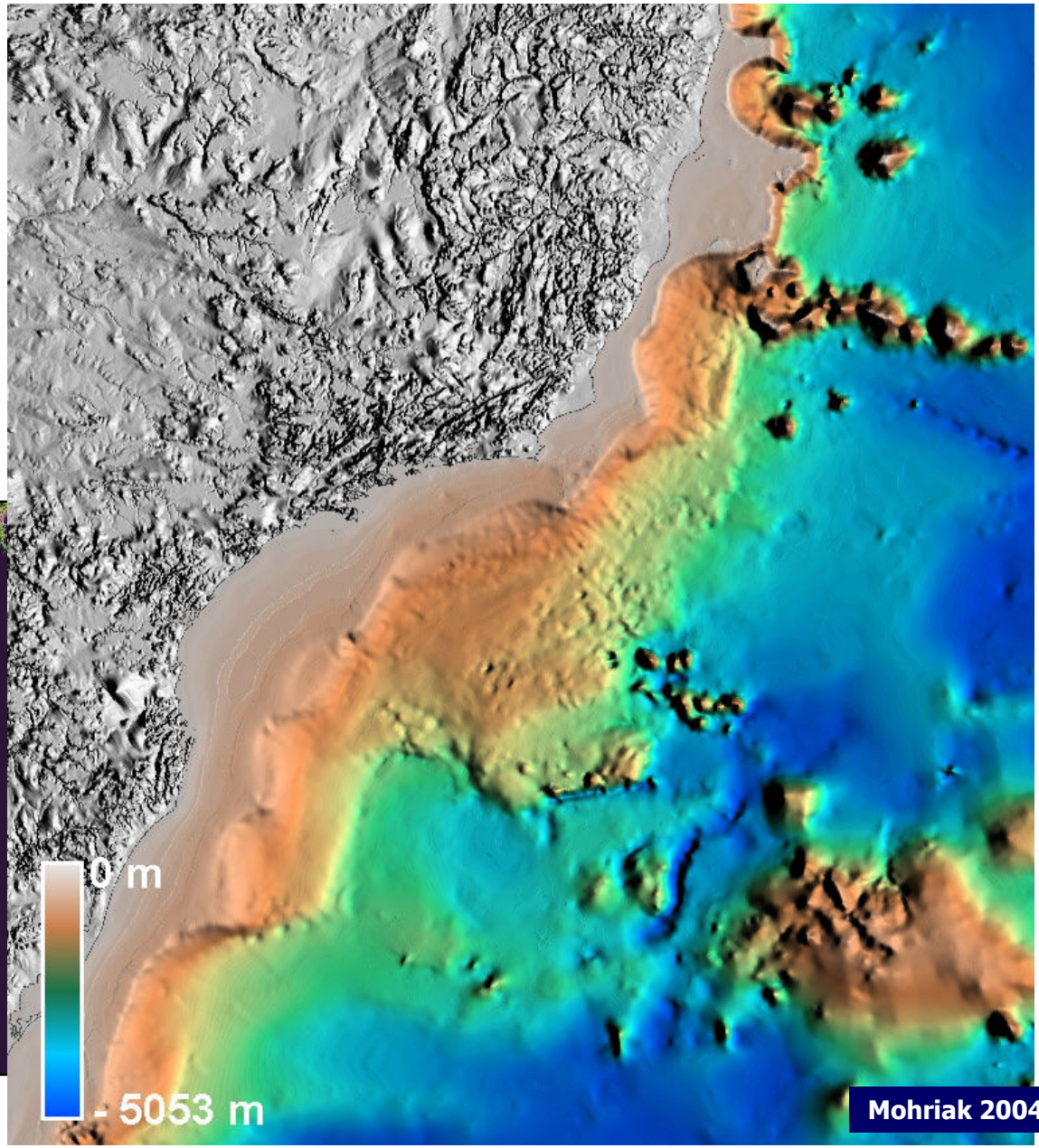
http://www.flickr.com/photos/jonathanenns/2696368555/sizes/l/in/photostream/

Serra do Mar, Parati (RJ)

SE Brasil

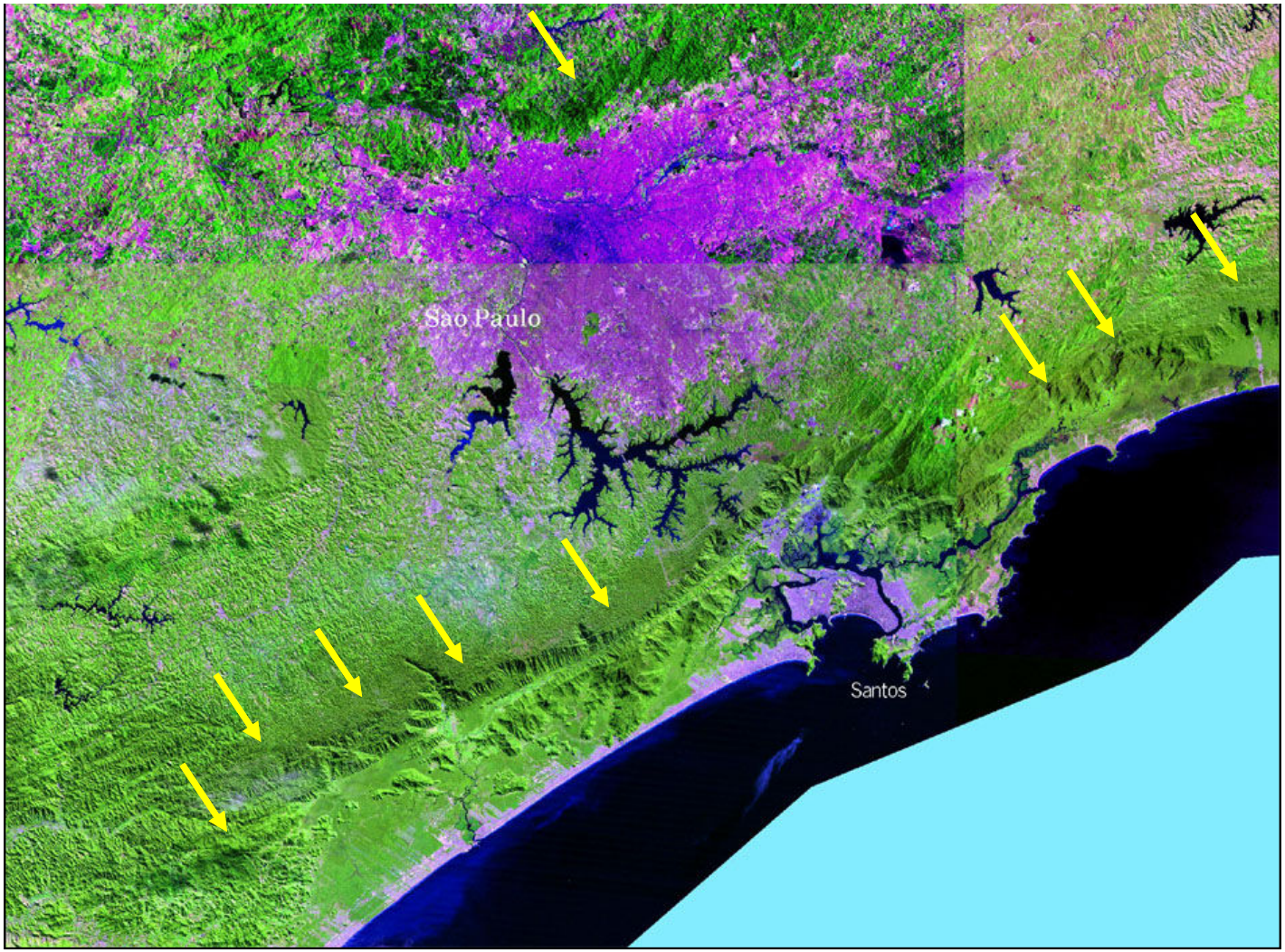
Topo-bathimetry and geomorphology of Southeastern South America



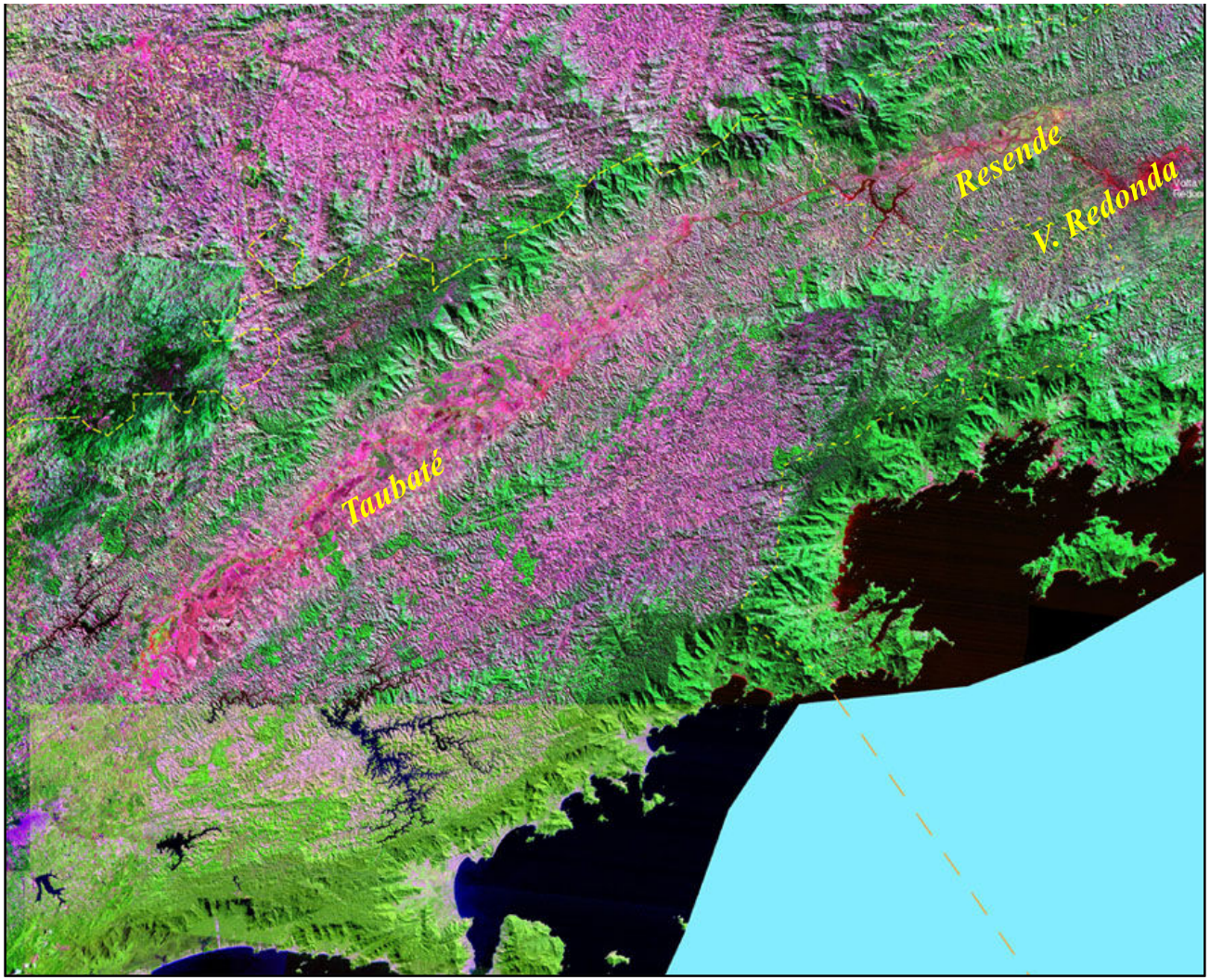


Mohriak 2004, modif. C. Bentz

Preserved Japi Surface bordering Serra do Mar and the Serra da Mantiqueira, north of São Paulo city (violet color)



Taubaté Basin: Mantiqueira and do Mar mountains



Conclusions

- **Studying Geology and relief of South America involves reconstructing ancient seas, glaciers, deserts...**

- Evolution is divided into phases:
  - Archean and Proterozoic: ancient terranes plus fold-and-thrust belts
  - Phanerozoic: unfolded sedimentary basins
  - Relief
    - **Differential erosion – vast regional erosion surfaces – uplifts**

References

Almeida F.F.M. de. 1976. The system of continental rifts bordering the Santos Basin, Brazil. *Anais da Academia Brasileira de Ciências,* **48**(supl.):15-26. *(Proceedings of the International Symposium on Continental Margins of Atlantic Type,* October 1975).

Almeida F.F.M. de, Brito-Neves B.B.de, Carneiro C.D.R. 2000. Origin and evolution of the South-American Platform. *Earth Science Reviews,* **50**(1-2):77-111.

Almeida F.F.M.de & Carneiro C.D.R. 1998. Origem e evolução da Serra do Mar. *Rev. Bras. Geoc.* **28**(2):135-150. URL: http://bjg.siteoficial.ws/1998/n.2/3.pdf.

Almeida F.F.M.de & Carneiro C.D.R. 2004. Inundações marinhas fanerozóicas no Brasil e recursos minerais associados. In: Mantesso Neto V., Bartorelli, A., Carneiro C.D.R., Brito-Neves B.B. orgs. 2004. *Geologia do Continente Sul-Americano*: Evolução da obra de Fernando Flávio Marques de Almeida. São Paulo: Ed. Beca. p. 43-60. (Cap. 3).

Azevedo R.L.M.de 2004. Paleoceanografia e a evolução do Atlântico Sul no Albiano. *B. Geoci. PETROBRAS*, **12**(2):231-249. maio/nov. 2004.

Franco-Magalhaes A.O.B., Cuglieri M.A.A., Hackspacher P.C., Saad A.R. 2014. Long-term landscape evolution and post-rift reactivation in the southeastern Brazilian passive continental margin: Taubaté basin. *Int J Earth Sci (Geol Rundsch)*, **103:441-453**. DOI 10.1007/s00531-013-0967-4.

Hasui Y., Carneiro C.D.R., Almeida F.F.M.de, Bartorelli A. eds. 2012. *Geologia do Brasil*. São Paulo: Ed. Beca. 900p.

Macedo J.M. 1991. Evolução Tectônica da Bacia de Santos e áreas continentais adjacentes. In: Gabaglia G.P.R., Milani E.J. coords. *Origem e evolução de bacias sedimentares*. Rio de Janeiro. 1991. Petrobrás. p. 361-374.

Milani E.J. & Thomaz FILHO A. 2000. Sedimentary basins of South America. In CORDANI et al. Tectonic Evolution of South America.

Soares P.C., Landim P.M.B., Sinelli O., Wernick E., Wu F.T., Fiori A.P. 1977. Associações litológicas do Subgrupo Itararé e sua interpretação ambiental. *Rev. Bras. Geoc.*, **7**(2):131-149.

Vesely F.F. & Assine M.L. 2004. Seqüências e tratos de sistemas deposicionais do Grupo Itararé, norte do Estado do Paraná. *Rev. Bras. Geoc.*, **34**(2):219-230.

Washburne C.W. 1930. *Petroleum geology of the state of São Paulo*. Com. Geogr. Geol. São Paulo, Brasil. p. 1-282. (Bol. 22).

Zalán P.V. 2004. Evolução fanerozóica das bacias sedimentares brasileiras. In: Mantesso Neto V., Bartorelli, A., Carneiro C.D.R., Brito-Neves B.B. orgs. 2004. *Geologia do Continente Sul-Americano*: Evolução da obra de Fernando Flávio Marques de Almeida. São Paulo: Ed. Beca. p. 595-612.

Thank you for your attention!