

# Conceitos básicos de Geologia Estrutural aplicados às bacias sedimentares

18 de agosto de 2014





fratura





falha





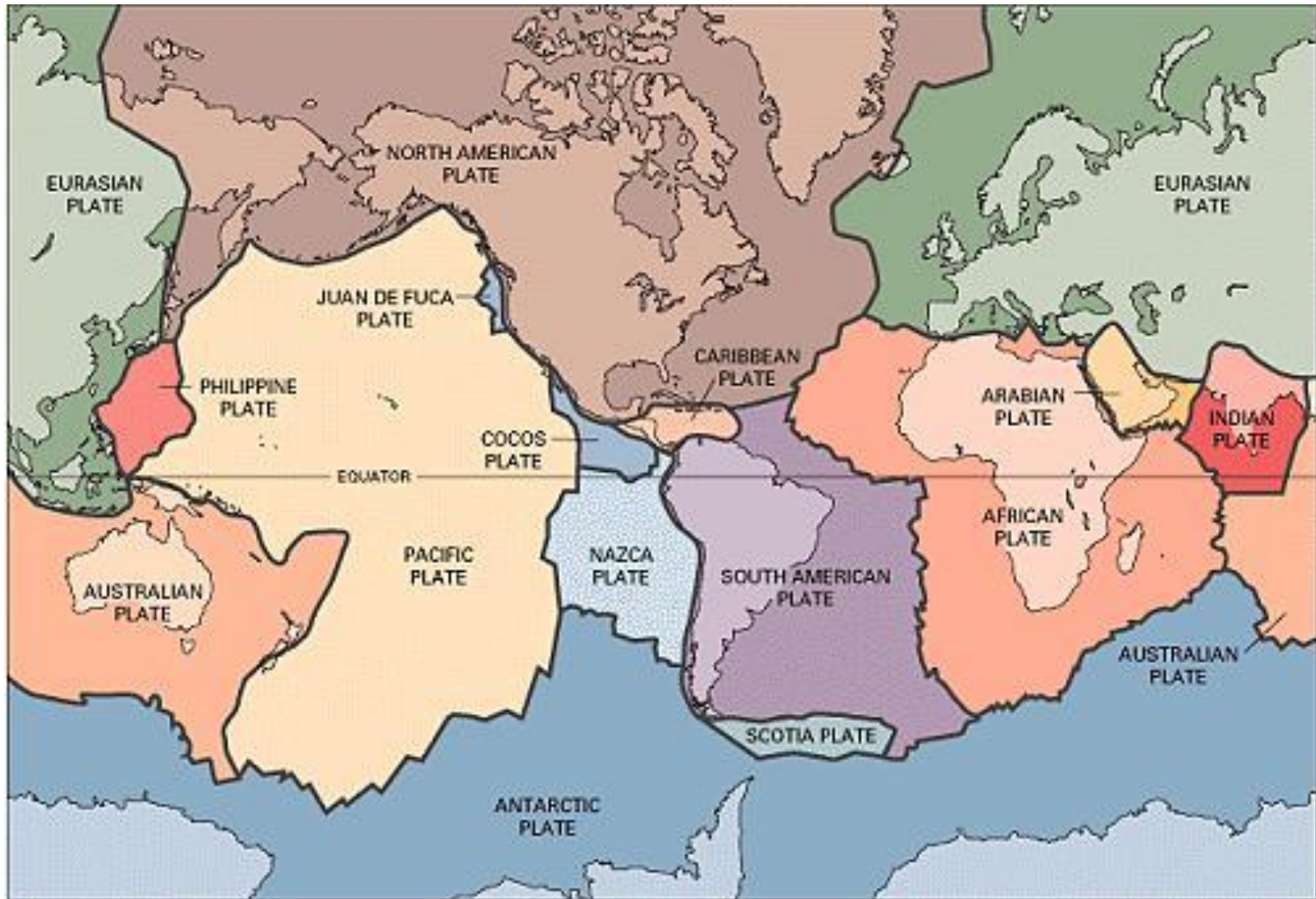
falha







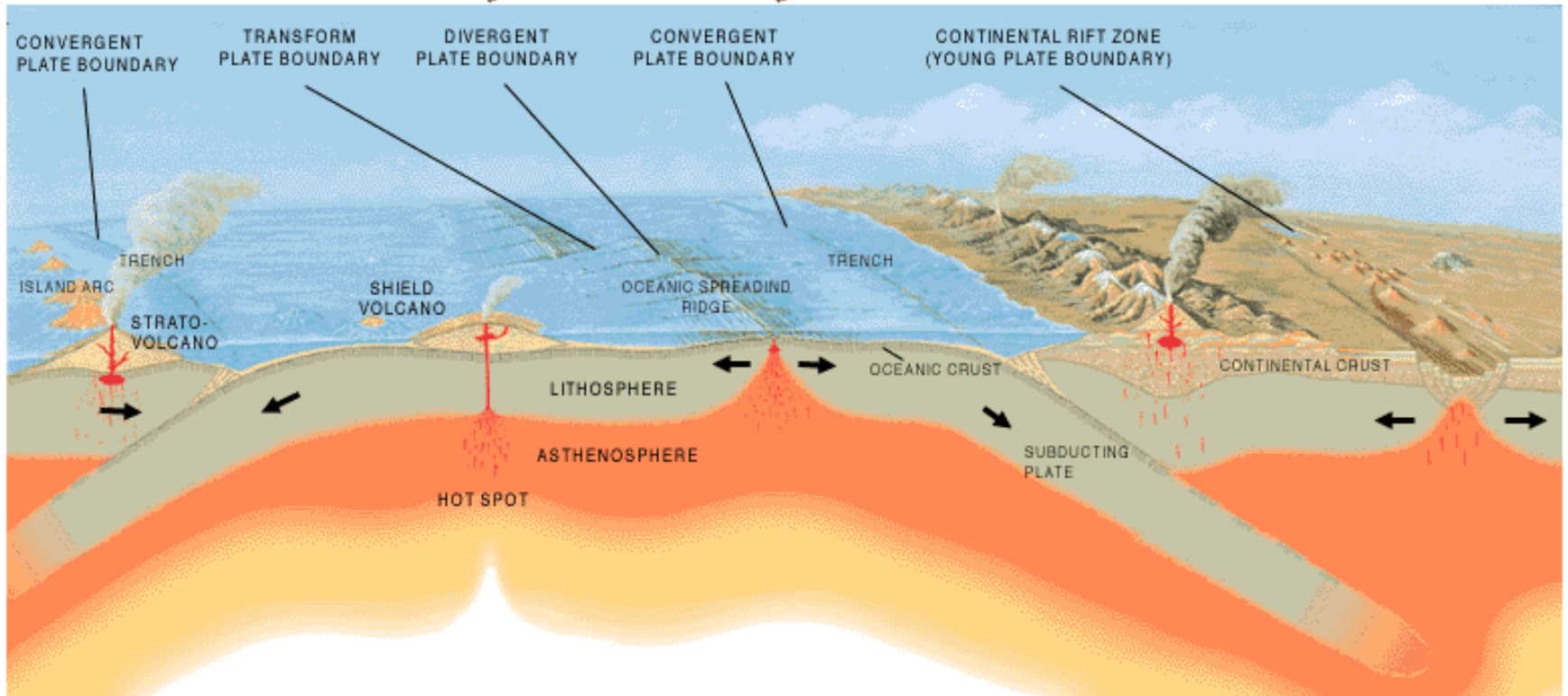
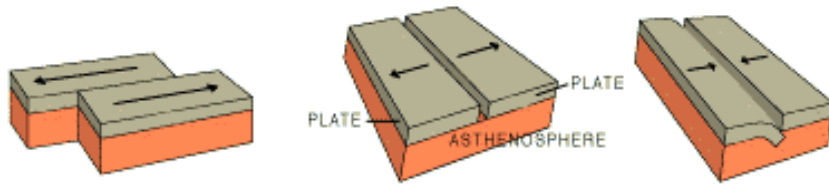
dobra



USGS

Três contextos tectônicos principais:

- *distensivos* - falhas normais
- *compressivos* - falhas inversas
- *transcorrentes* - falhas transcorrentes



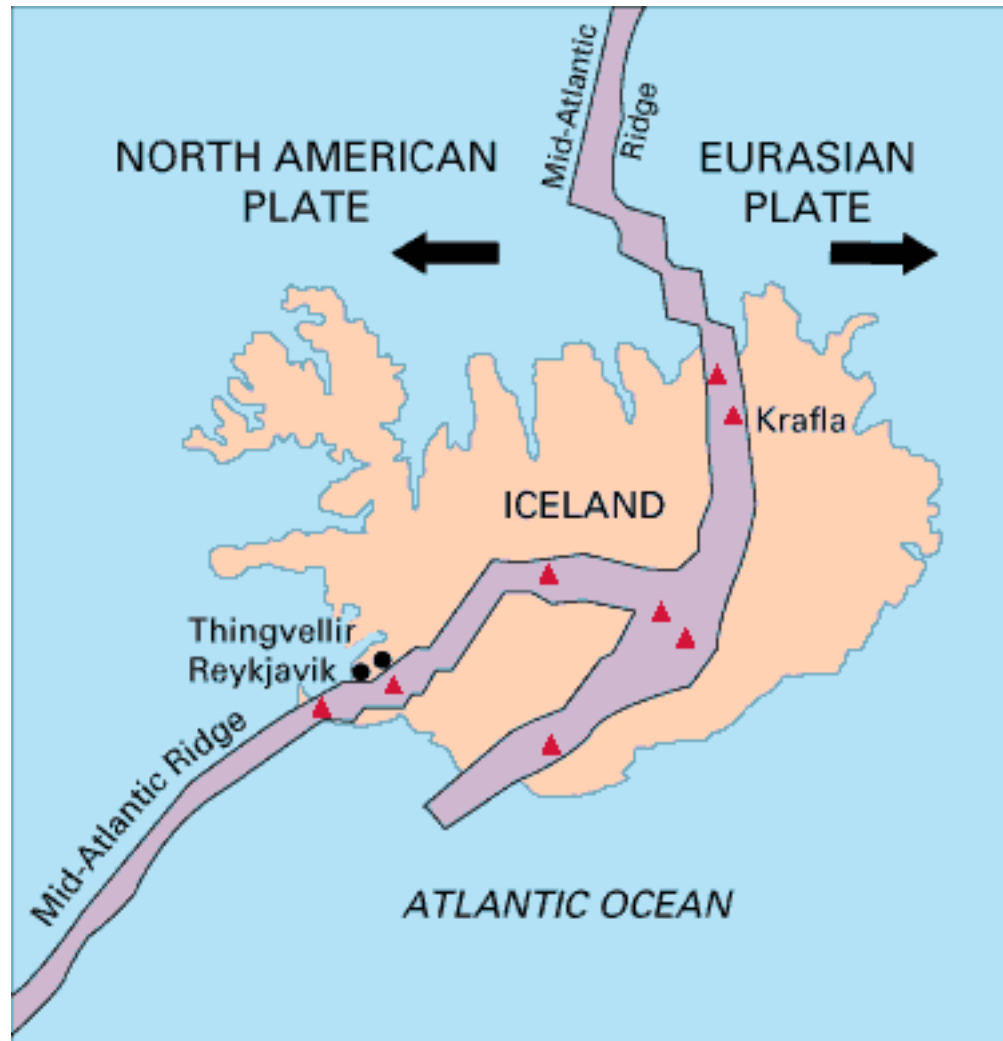
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USGS

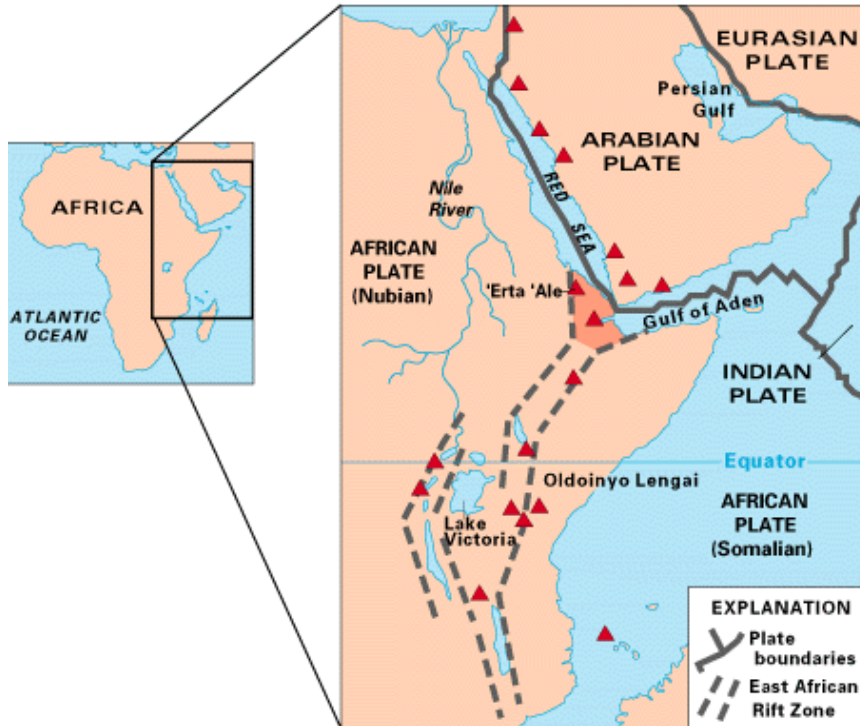


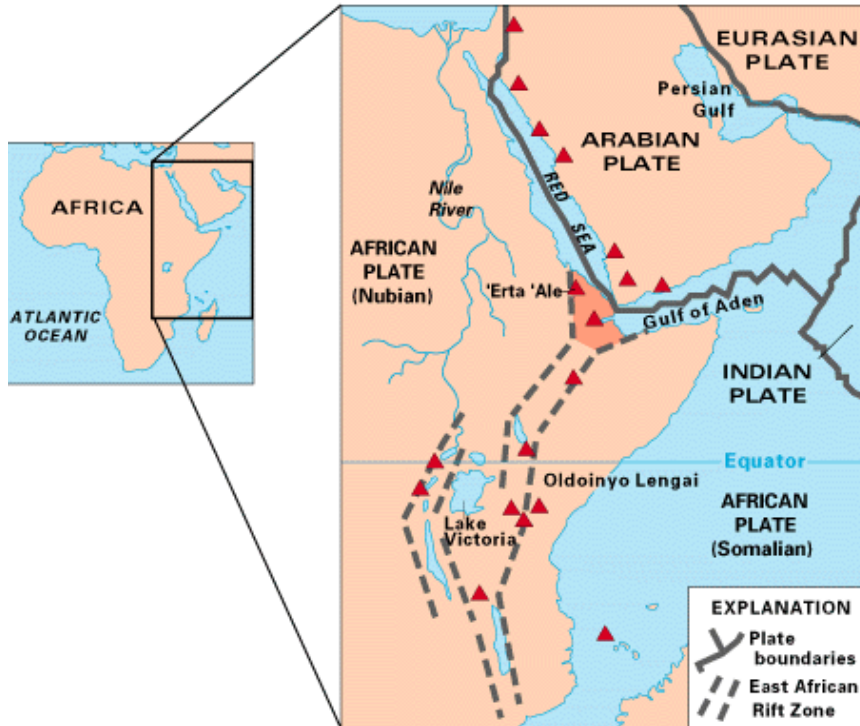




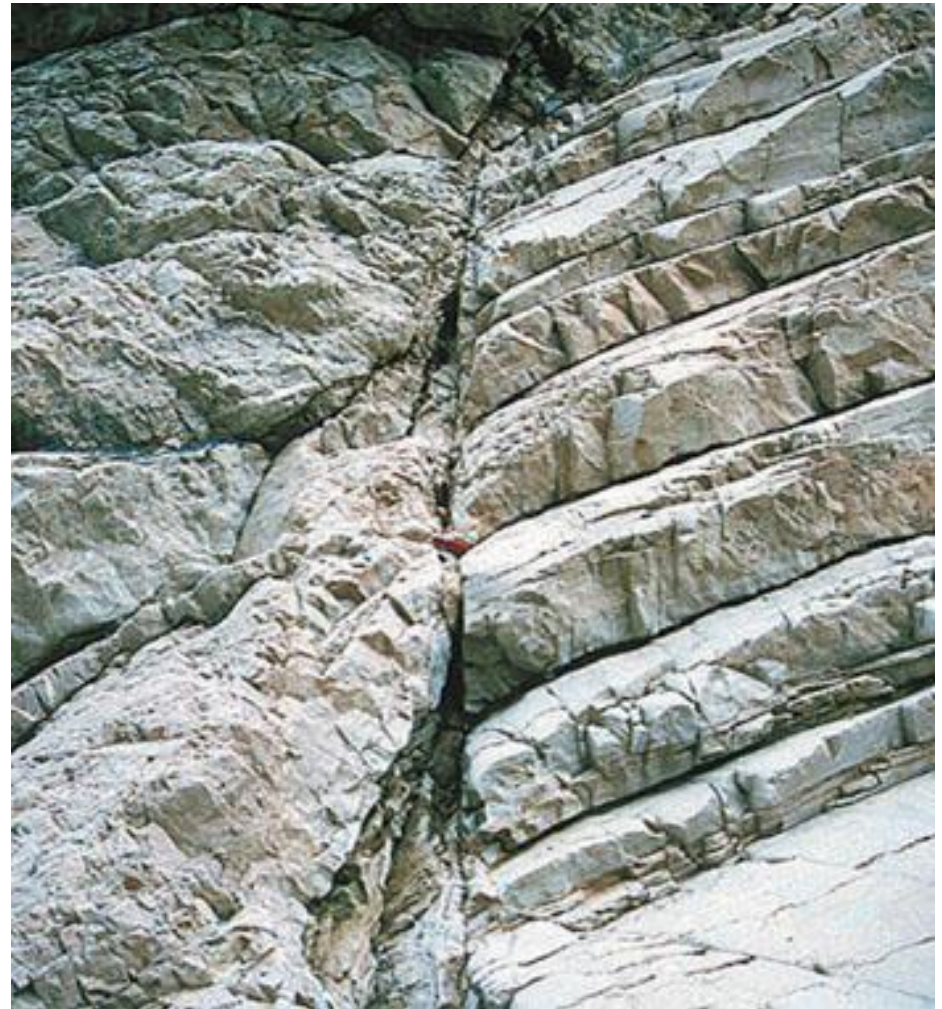
***Vulcão Krafla***















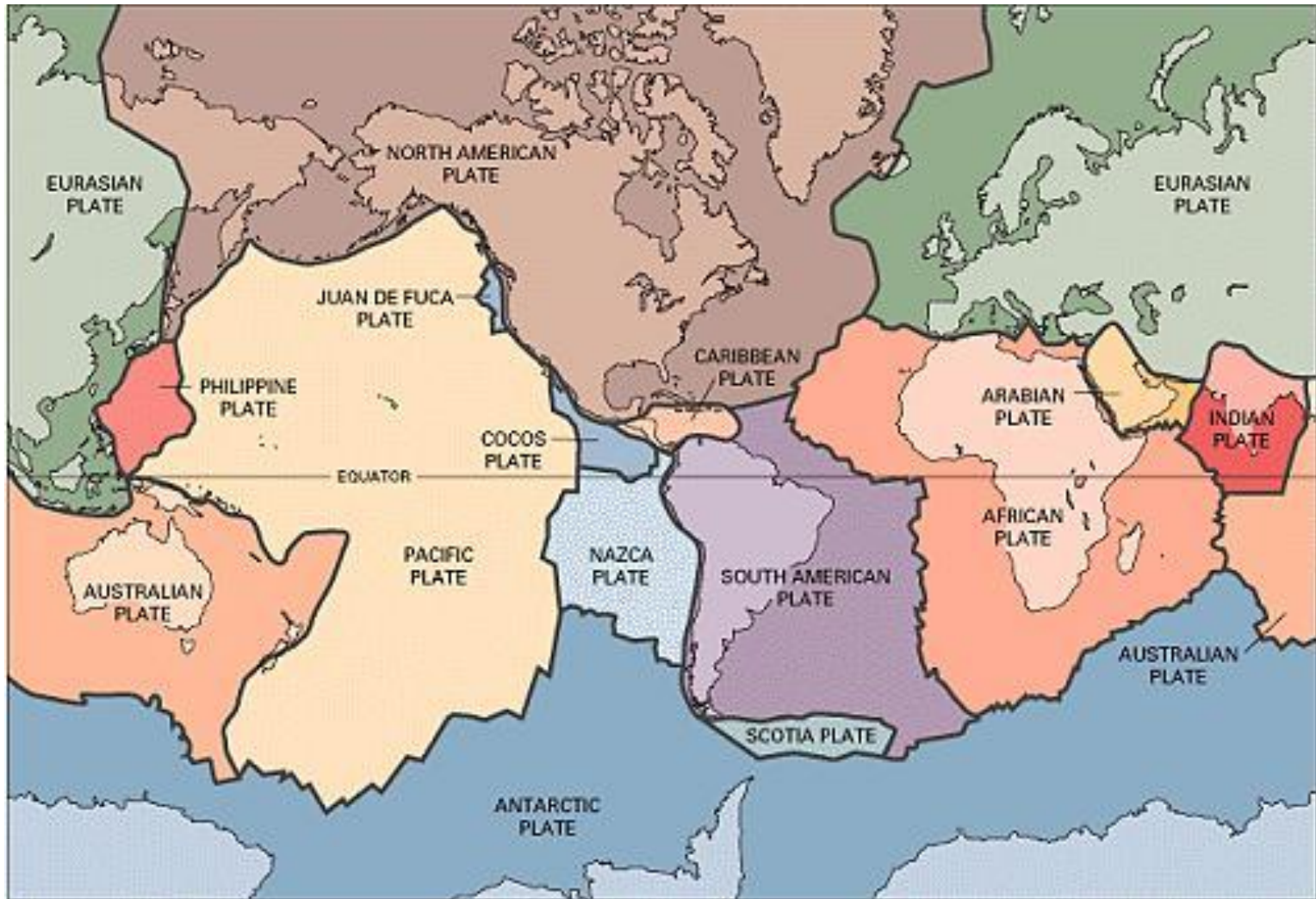




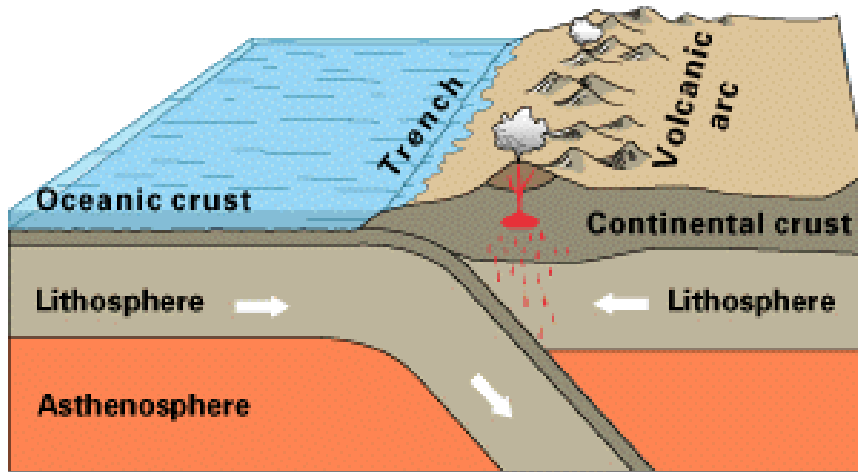


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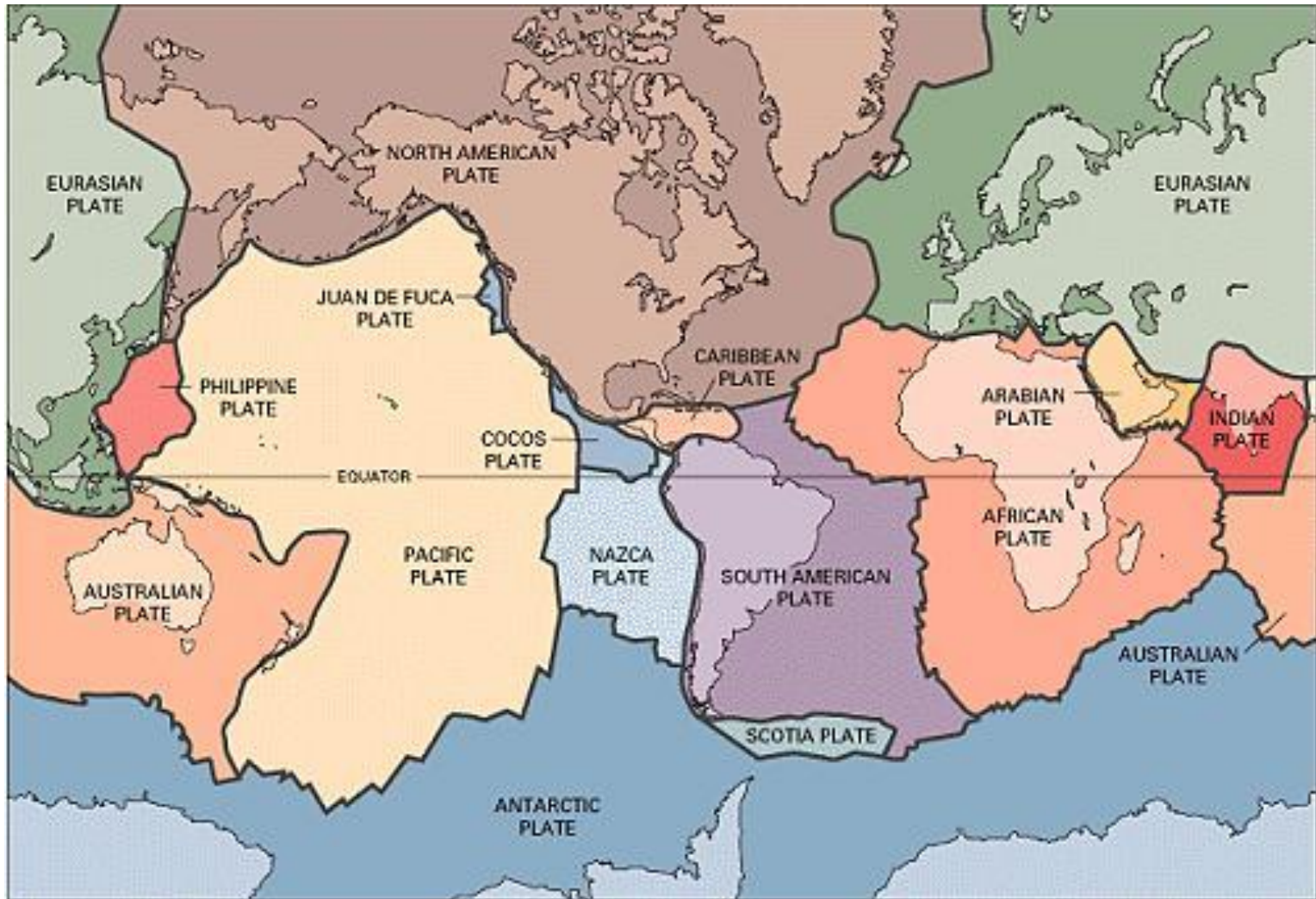


USGS

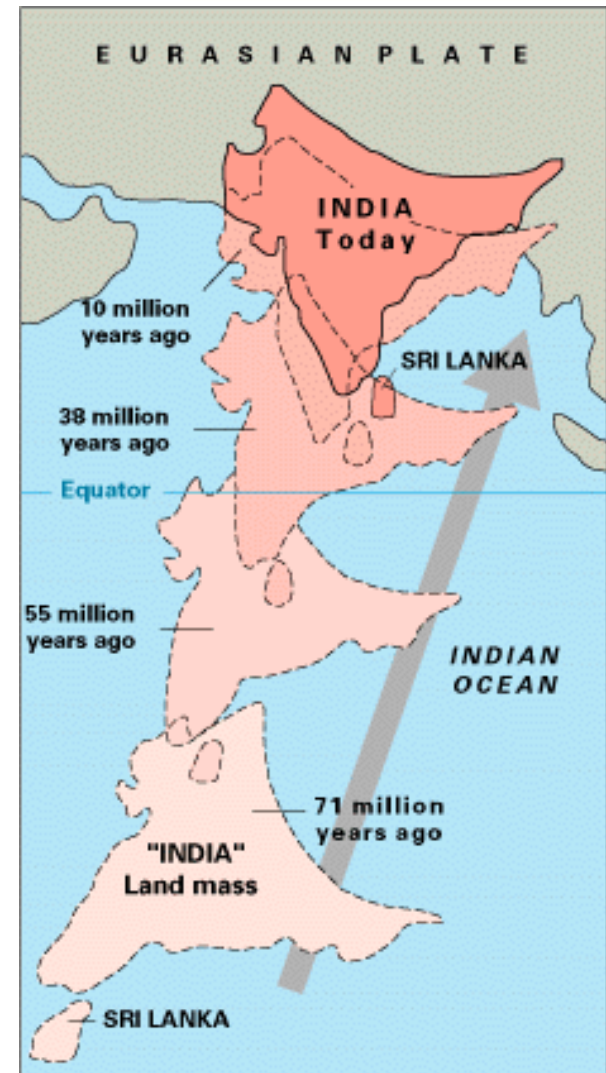
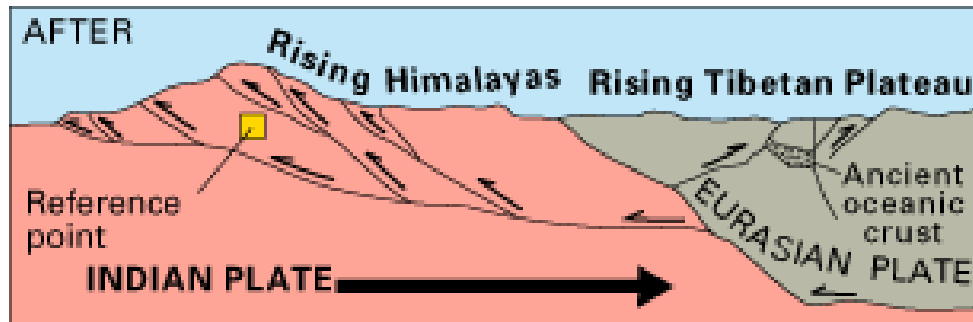
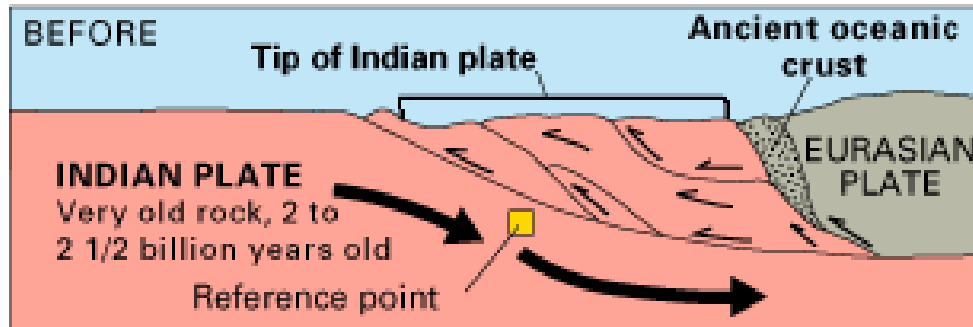


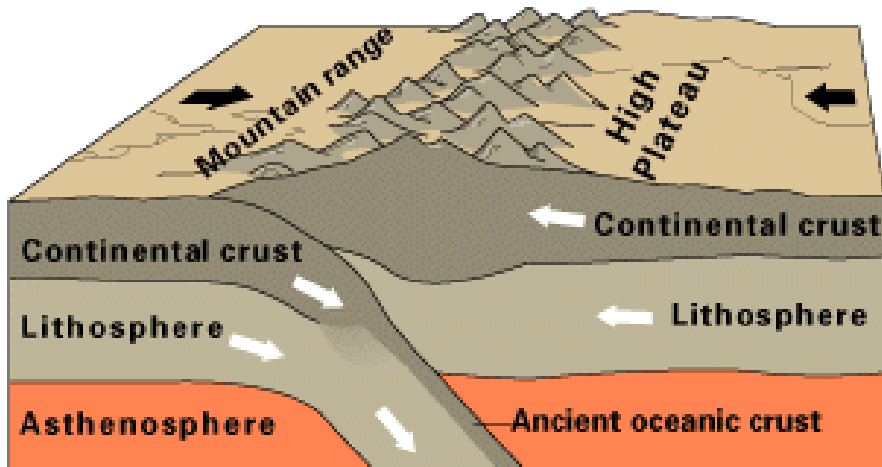
*Limite convergente entre  
crosta continental e crosta  
oceânica*





USGS



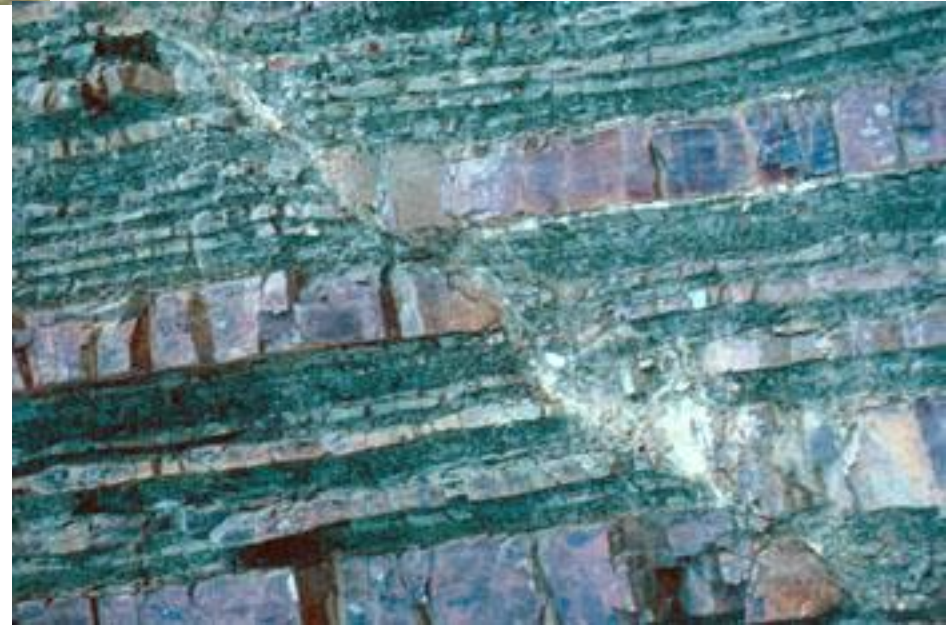


Continental-continental convergence

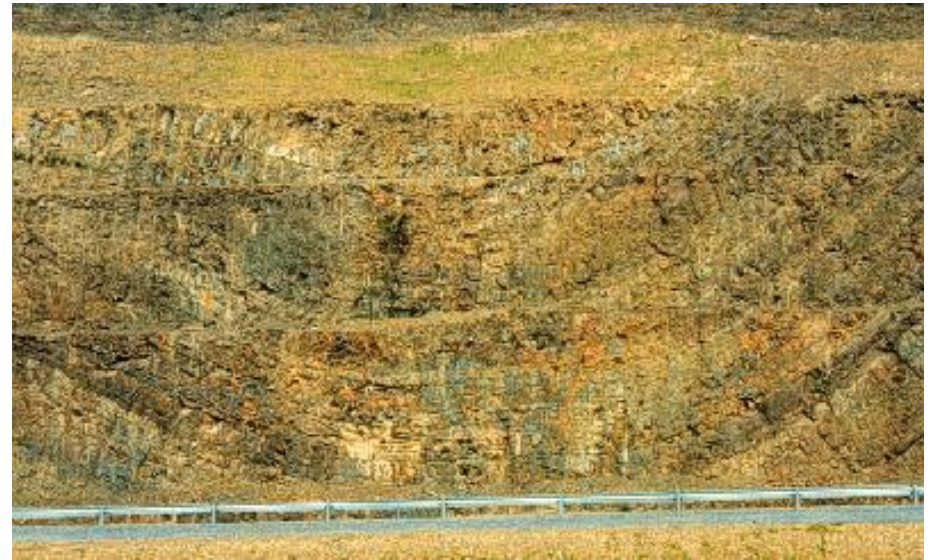


*Limite convergente entre crosta continental e crosta continental*





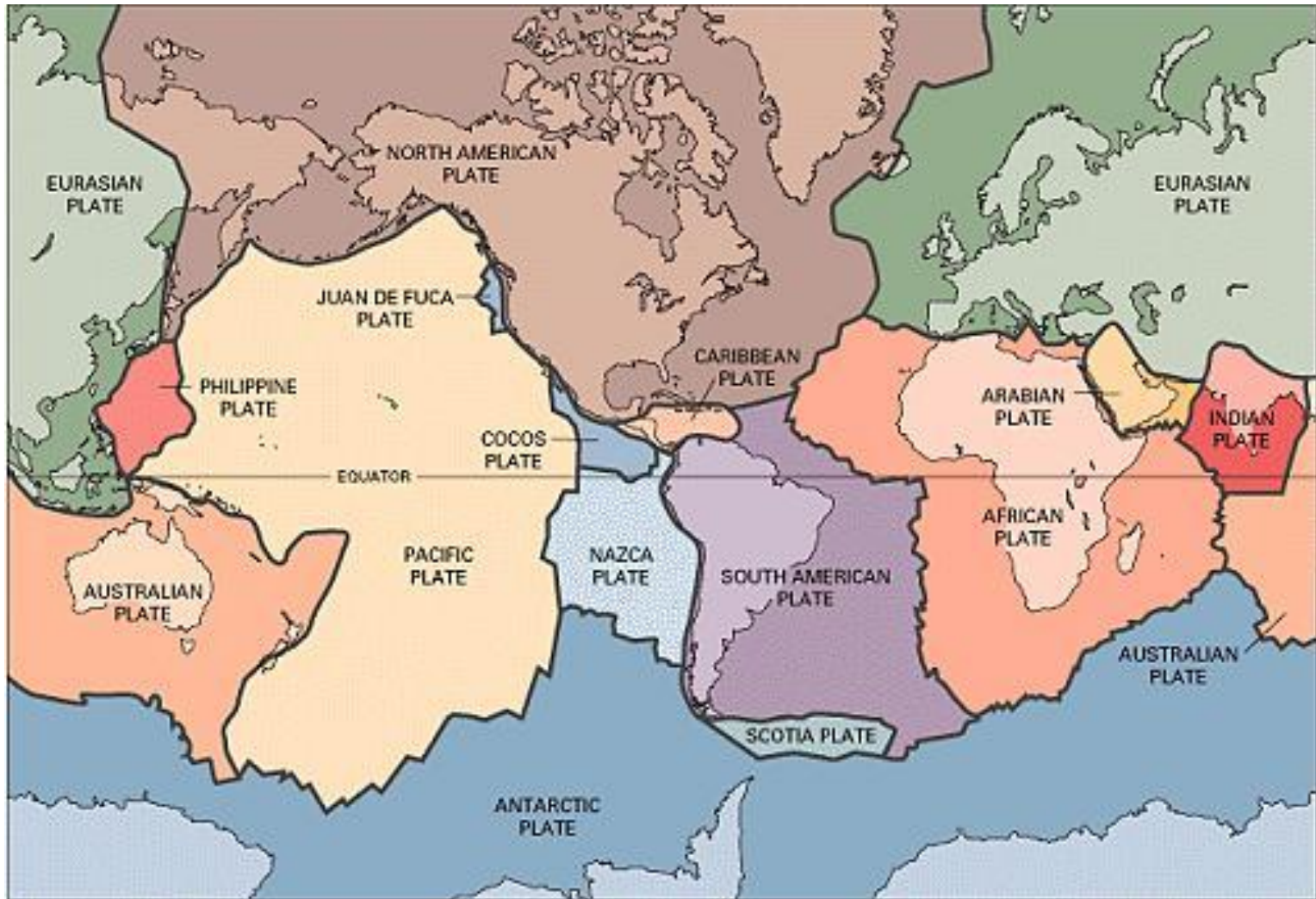




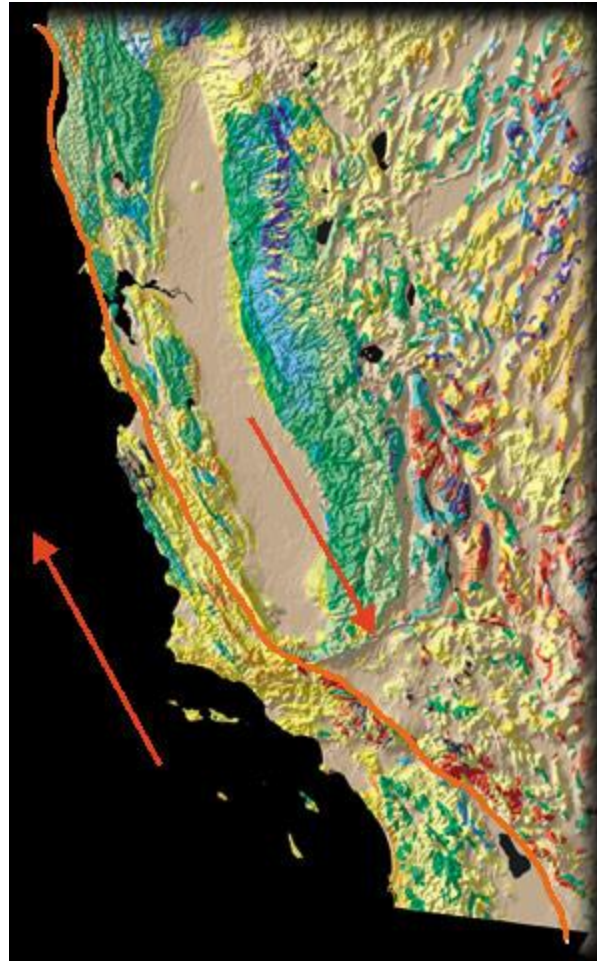


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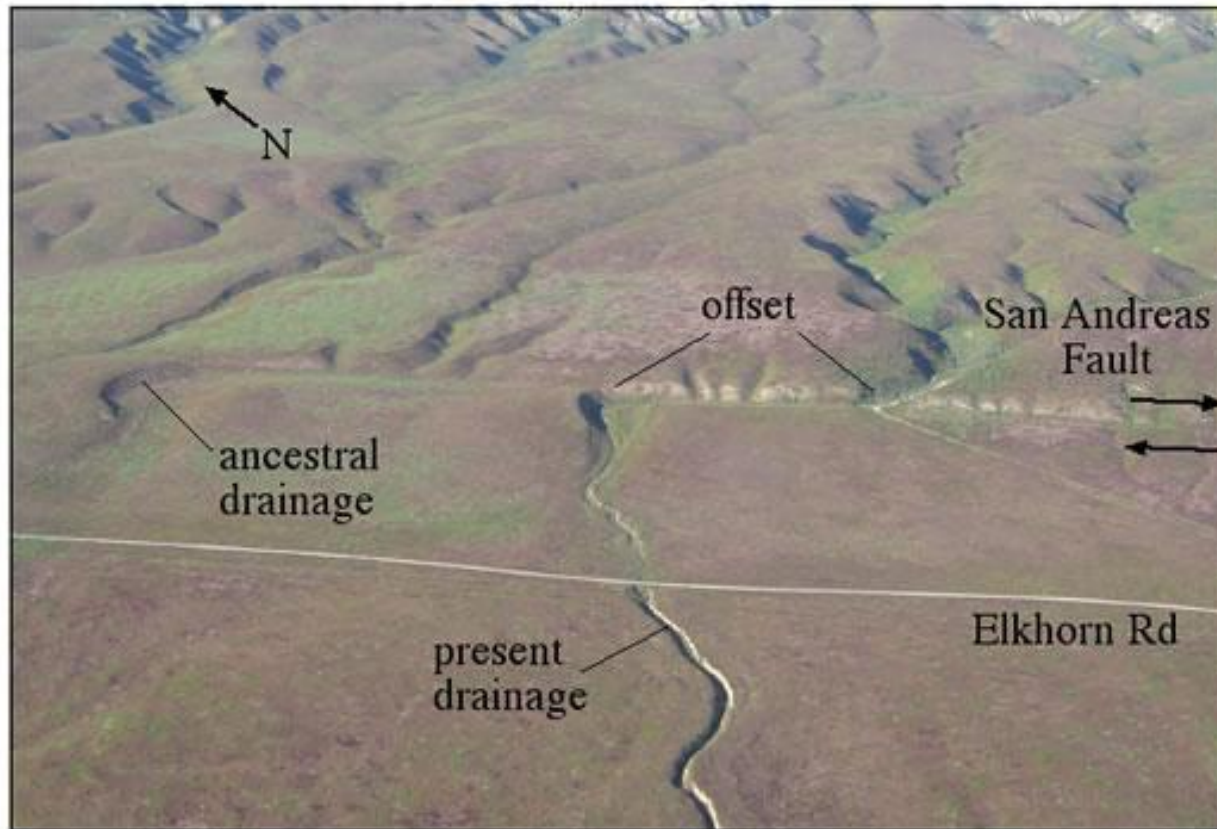


USGS

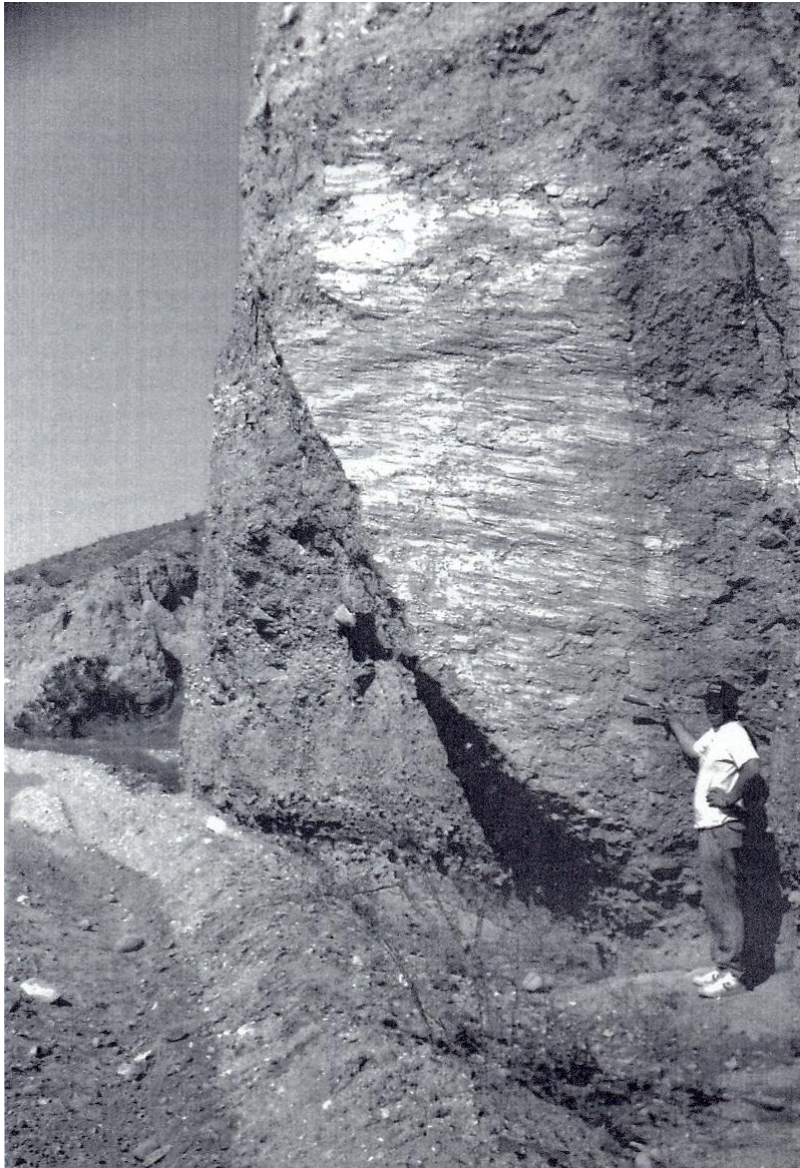




## Wallace Creek



~ 100 yards

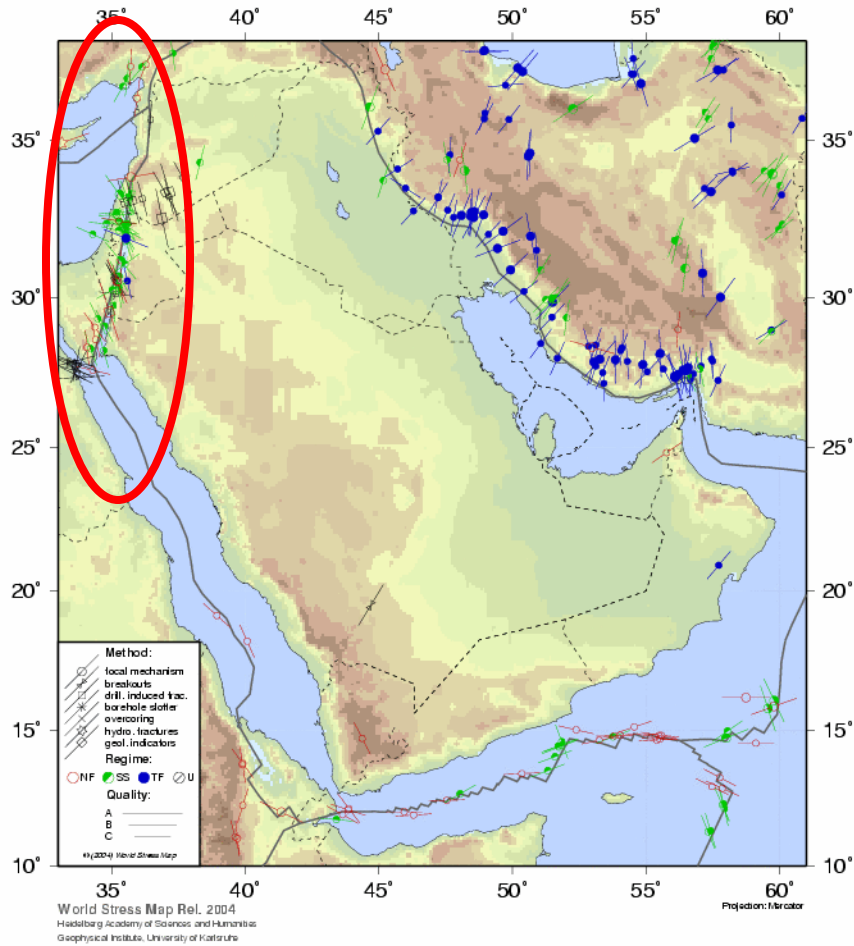


Estrias horizontais em falha  
transcorrente, Zona de Cisa-  
lhamento de San Andreas

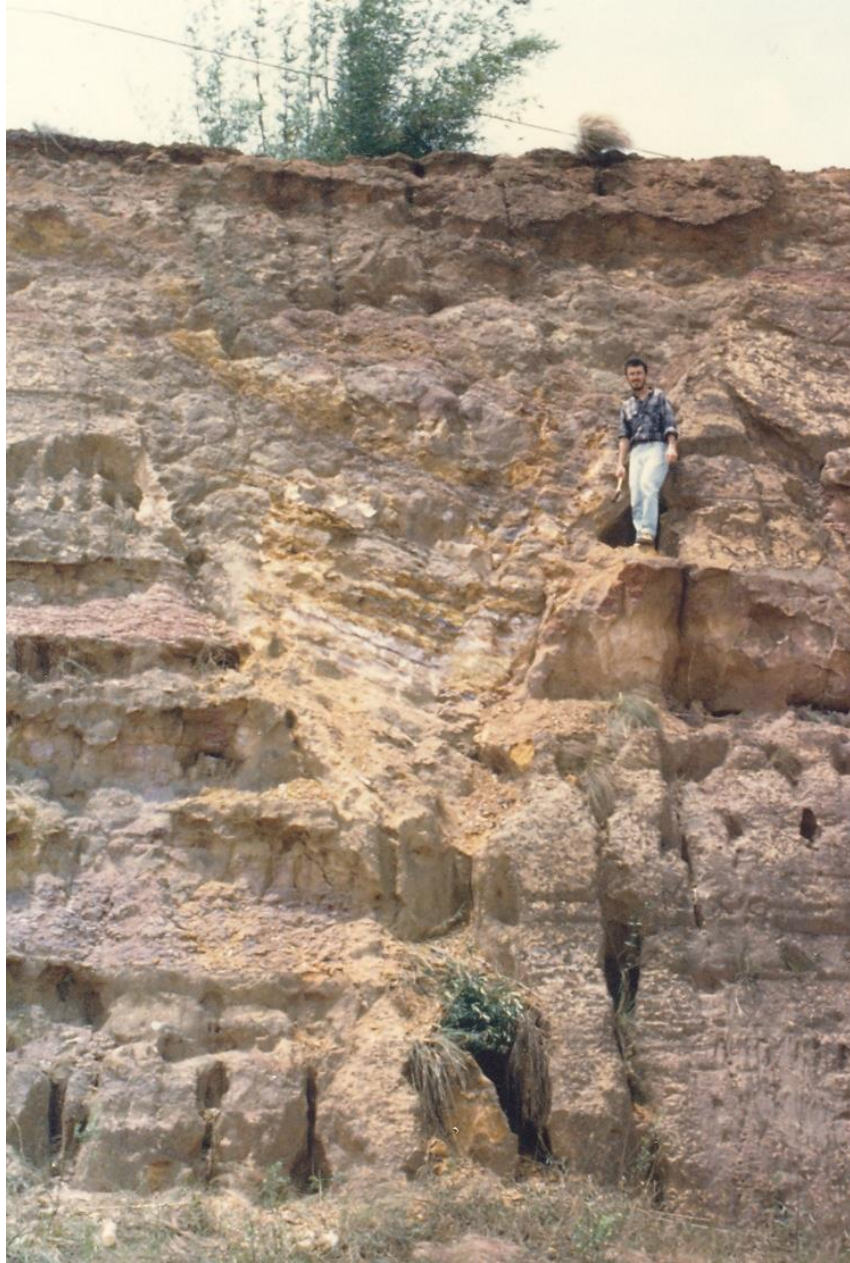
Corona (1993)

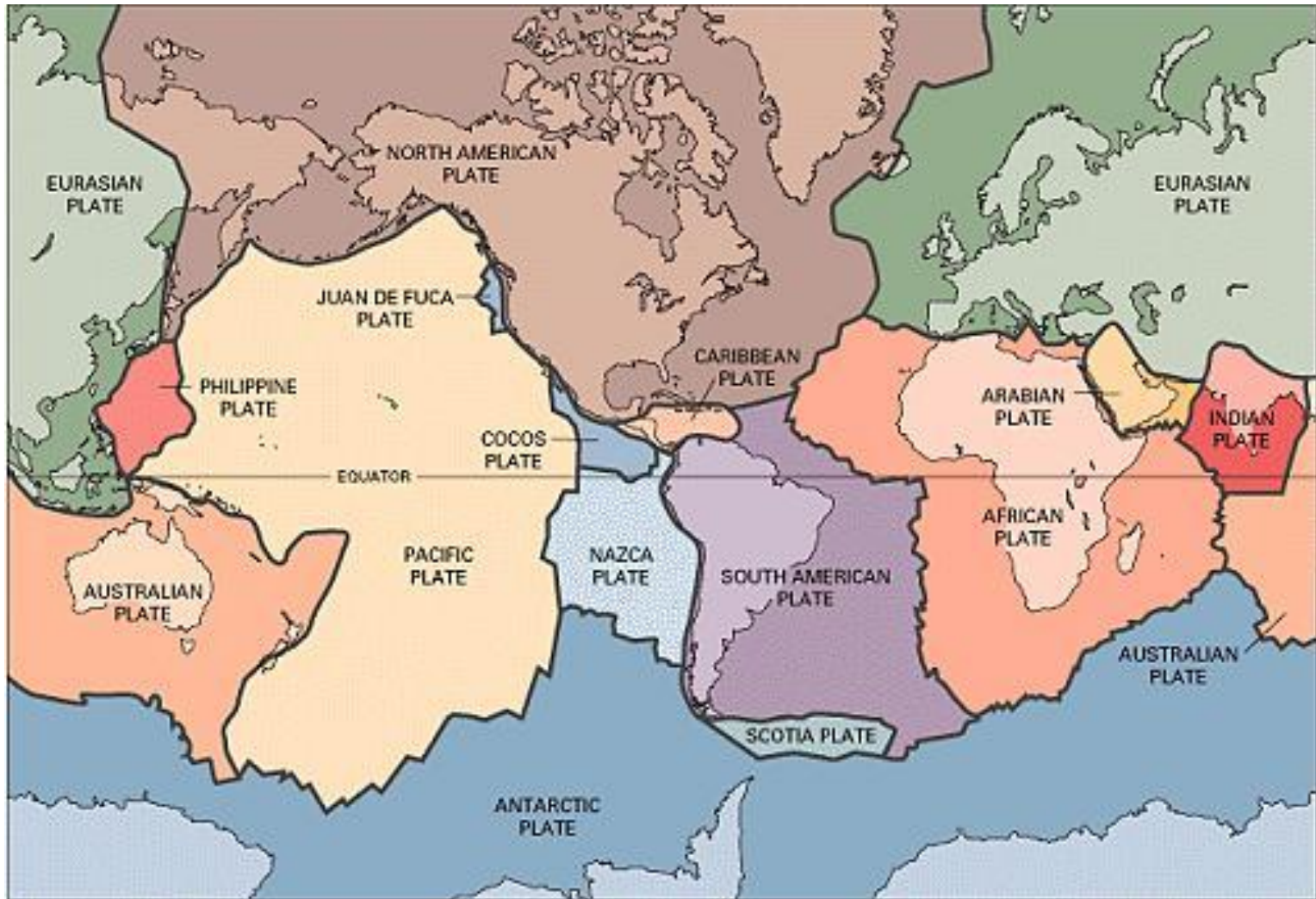




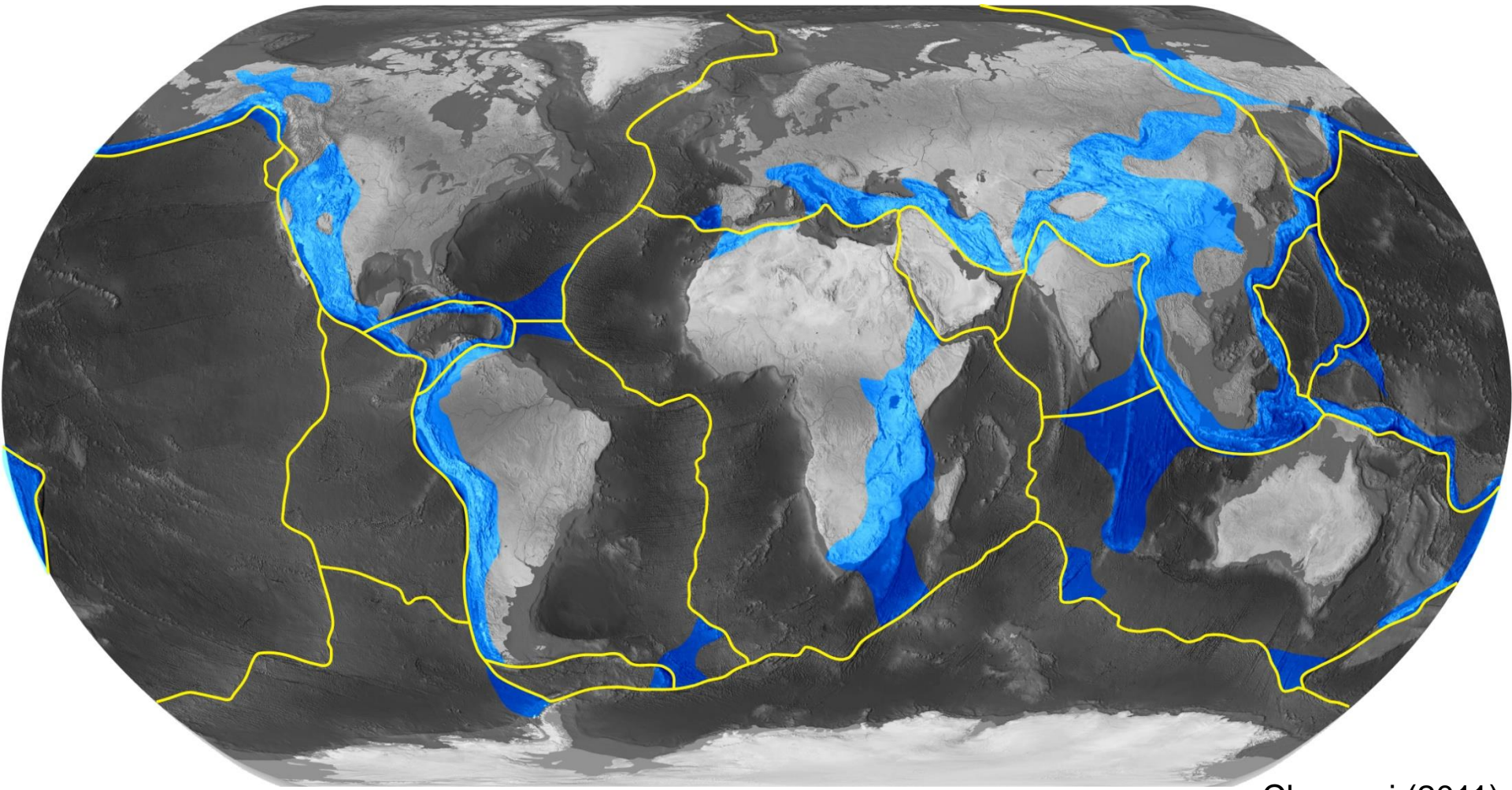


*Limite transforme*

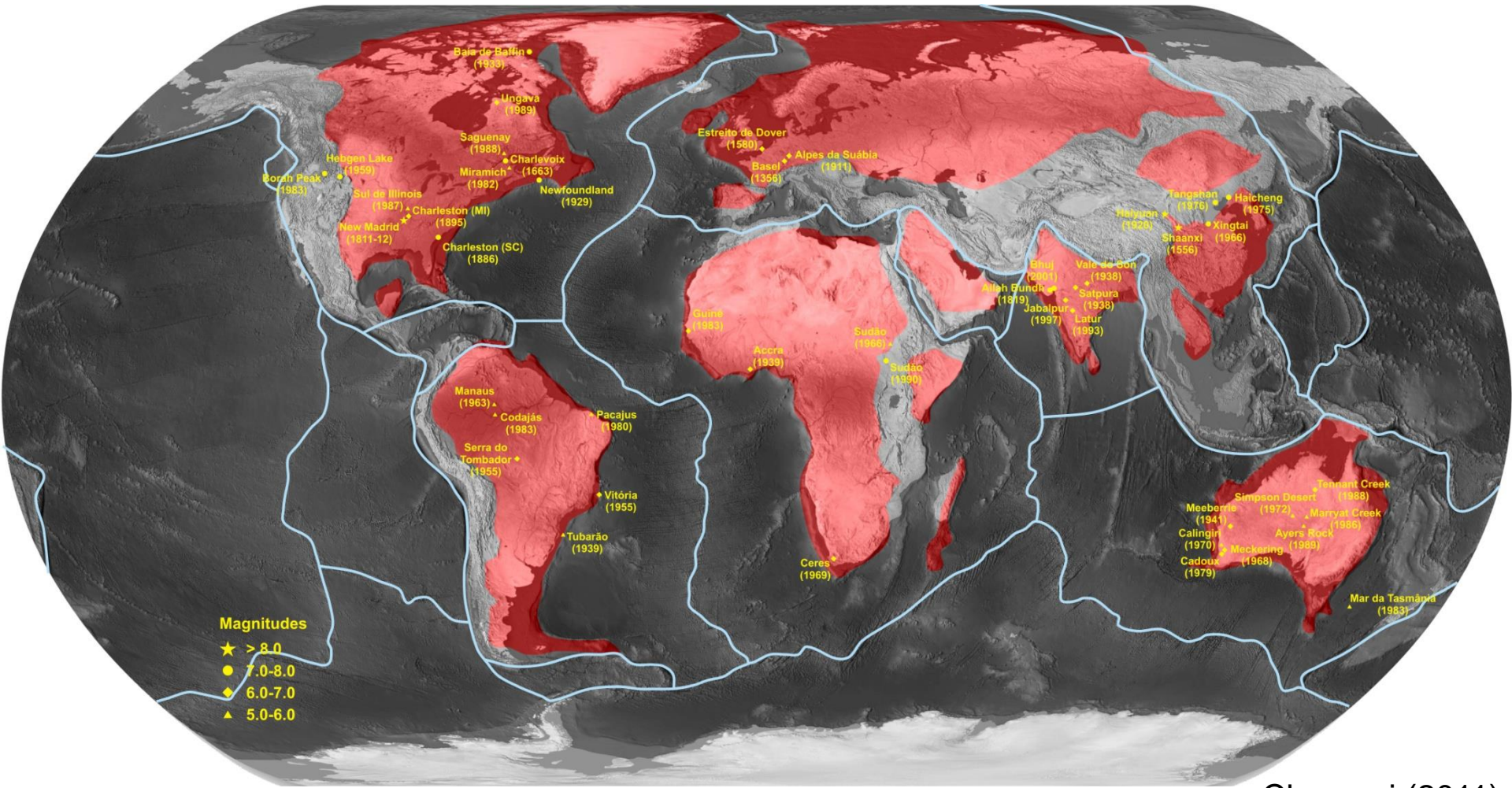




USGS



Chamani (2011)



Chamani (2011)

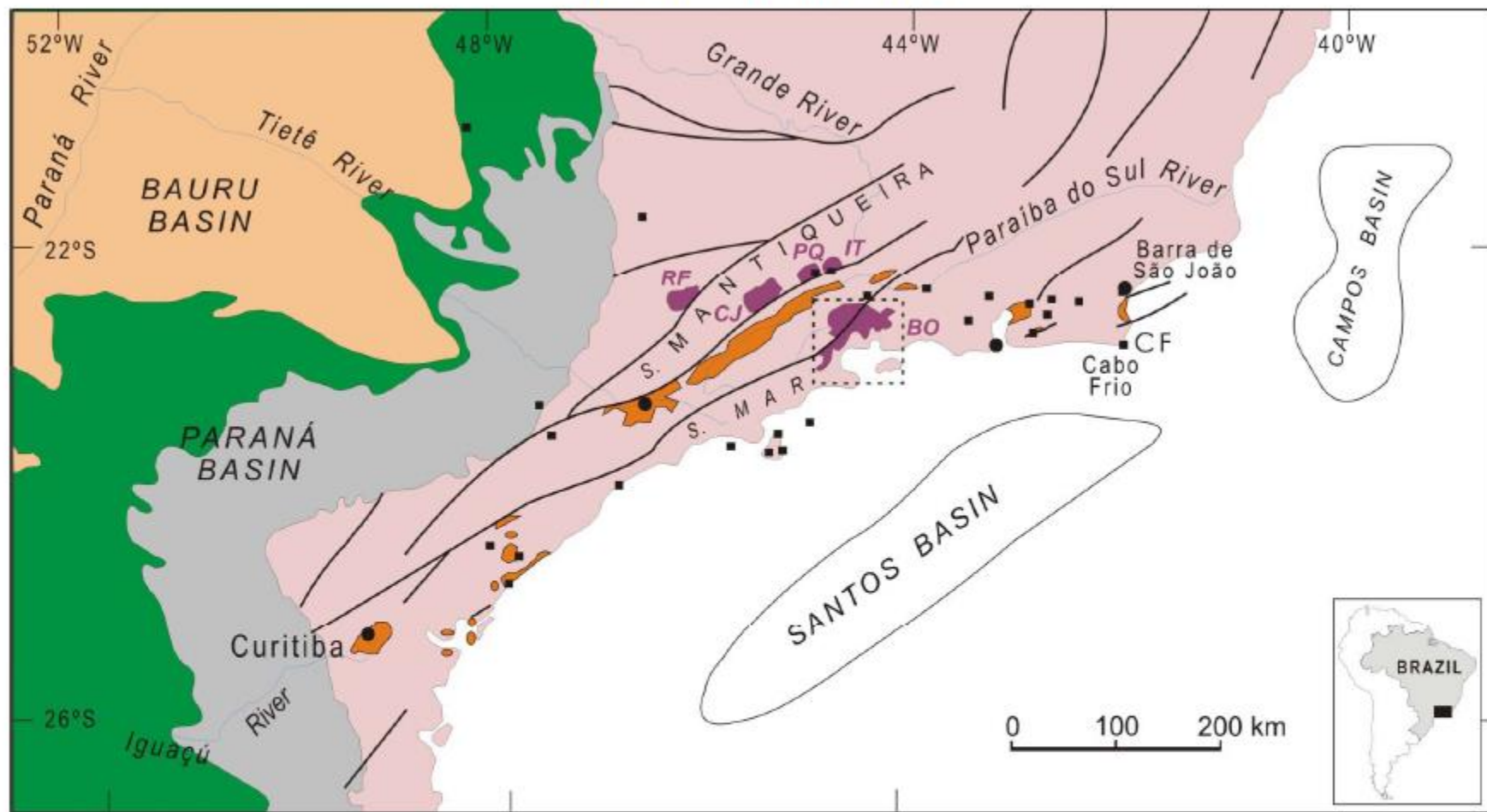


Chamani (2011)

- Falhas ativas durante a formação da bacia: tectônica geradora
- Falhas pós-sedimentares: tectônica deformadora (ou modificadora)

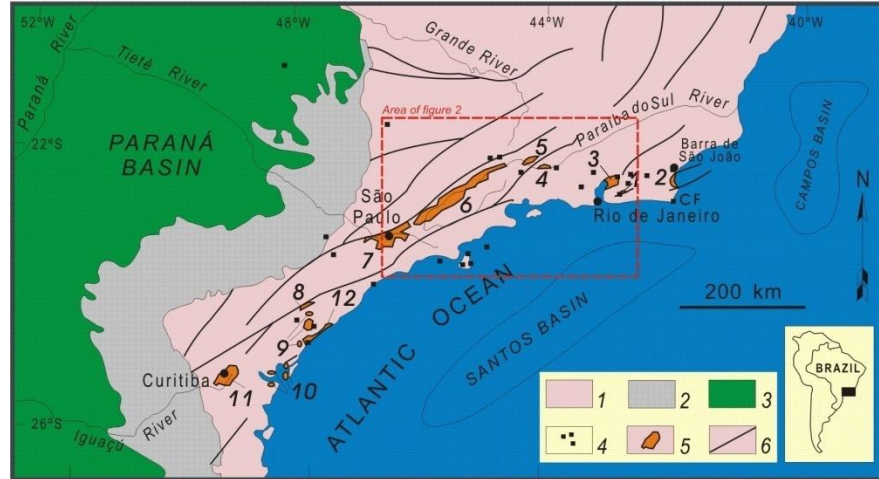


# GEOLOGICAL SETTING

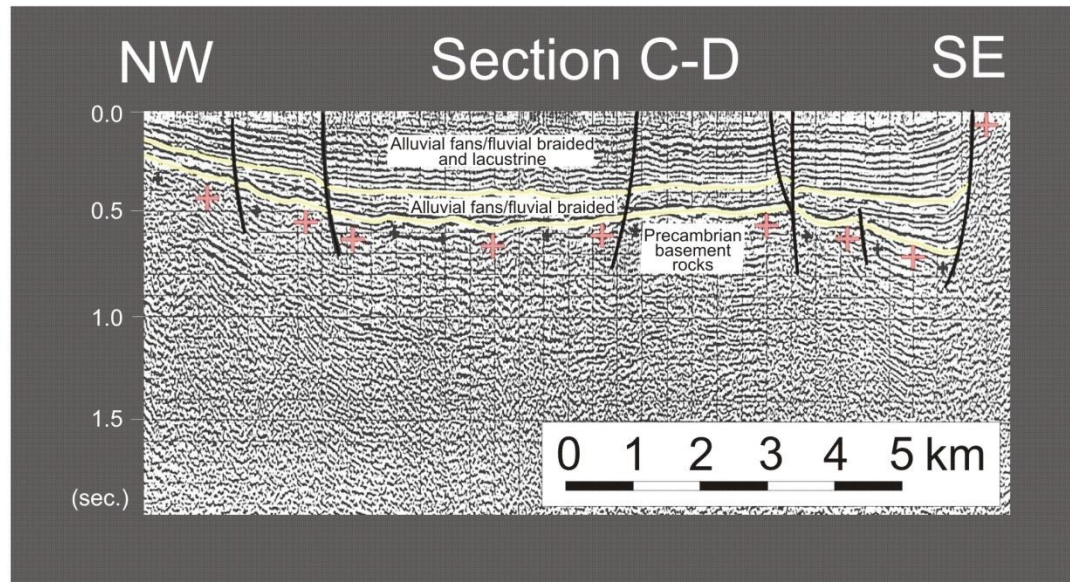
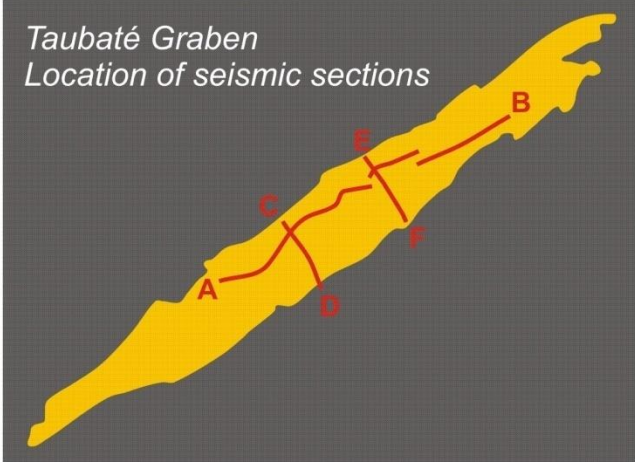


- |   |   |
|---|---|
| <ul style="list-style-type: none"> <li> Summit surfaces:<br/>BO—Bocaina Plateau, RF—Campos do Ribeirão Fundo<br/>CJ—Campos do Jordão Plateau, IT—Itatiaia Massif<br/>PQ—Passa-Quatro Massif</li> <li> Cenozoic basins of the continental rift of southeastern Brazil</li> <li> Mesozoic to Cenozoic alkaline rocks</li> <li> Cretaceous sedimentary rocks of the Bauru Basin</li> </ul> | <ul style="list-style-type: none"> <li> Early Cretaceous tholeiitic volcanic rocks of the Serra Geral Formation</li> <li> Paleozoic sedimentary rocks of the Paraná Basin</li> <li> Precambrian shear zones</li> <li> Precambrian basement rocks</li> </ul> |
|---|---|

Modified from Melo et al. (1985) and Riccomini et al. (2004).



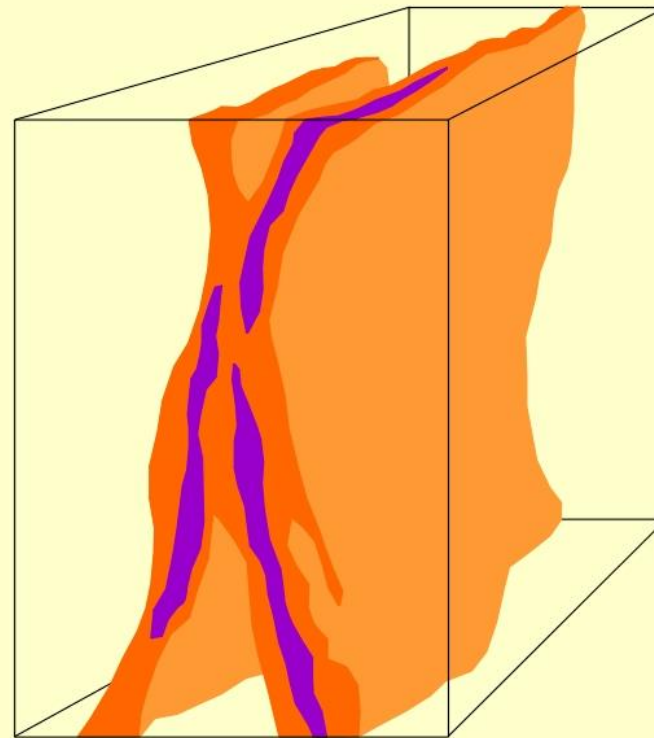
Taubaté Graben  
Location of seismic sections



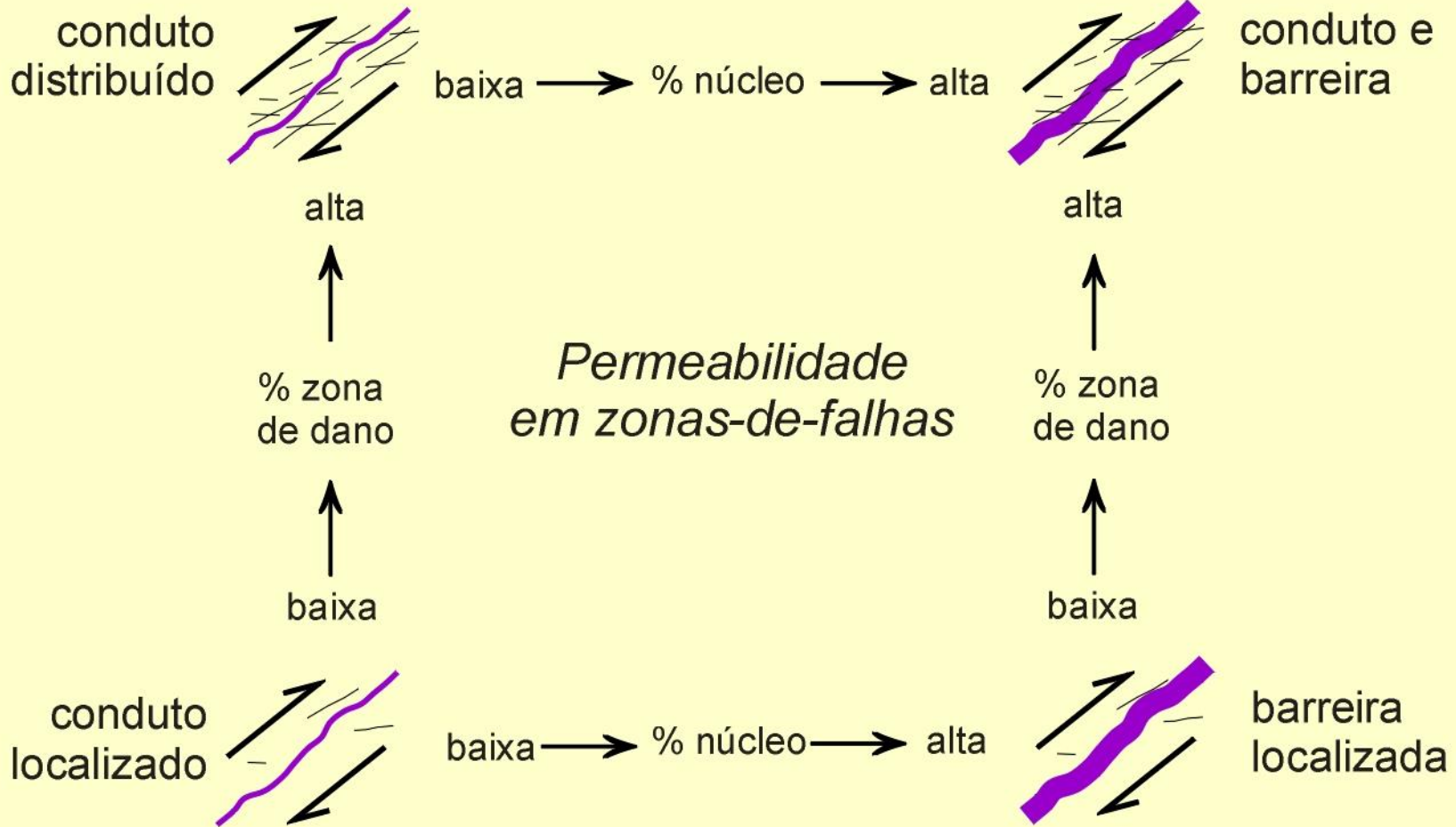
Reativação de falhas: zonas de falhas preexistentes reaproveitadas em eventos tectônicos mais jovens.

## Arquitetura de uma zona-de-falha

- núcleo**
  - moinha
  - cataclasito
  - milonito
  
- zona de dano**
  - pequenas falhas
  - juntas
  - veios
  - dobras
  
- protólito**
  - tipo de rocha
  - estruturas regionais

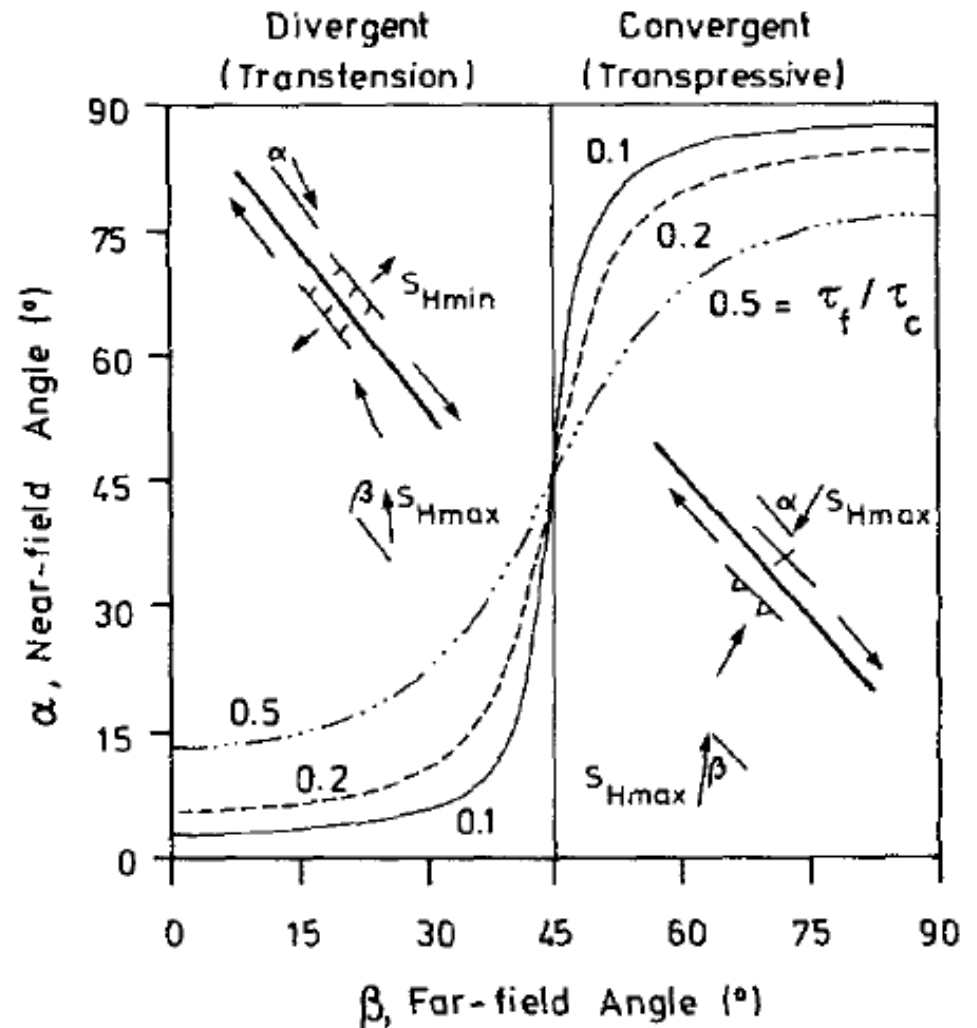


Modificado de Caine *et al.* 1996



Modificado de Caine *et al.* 1996

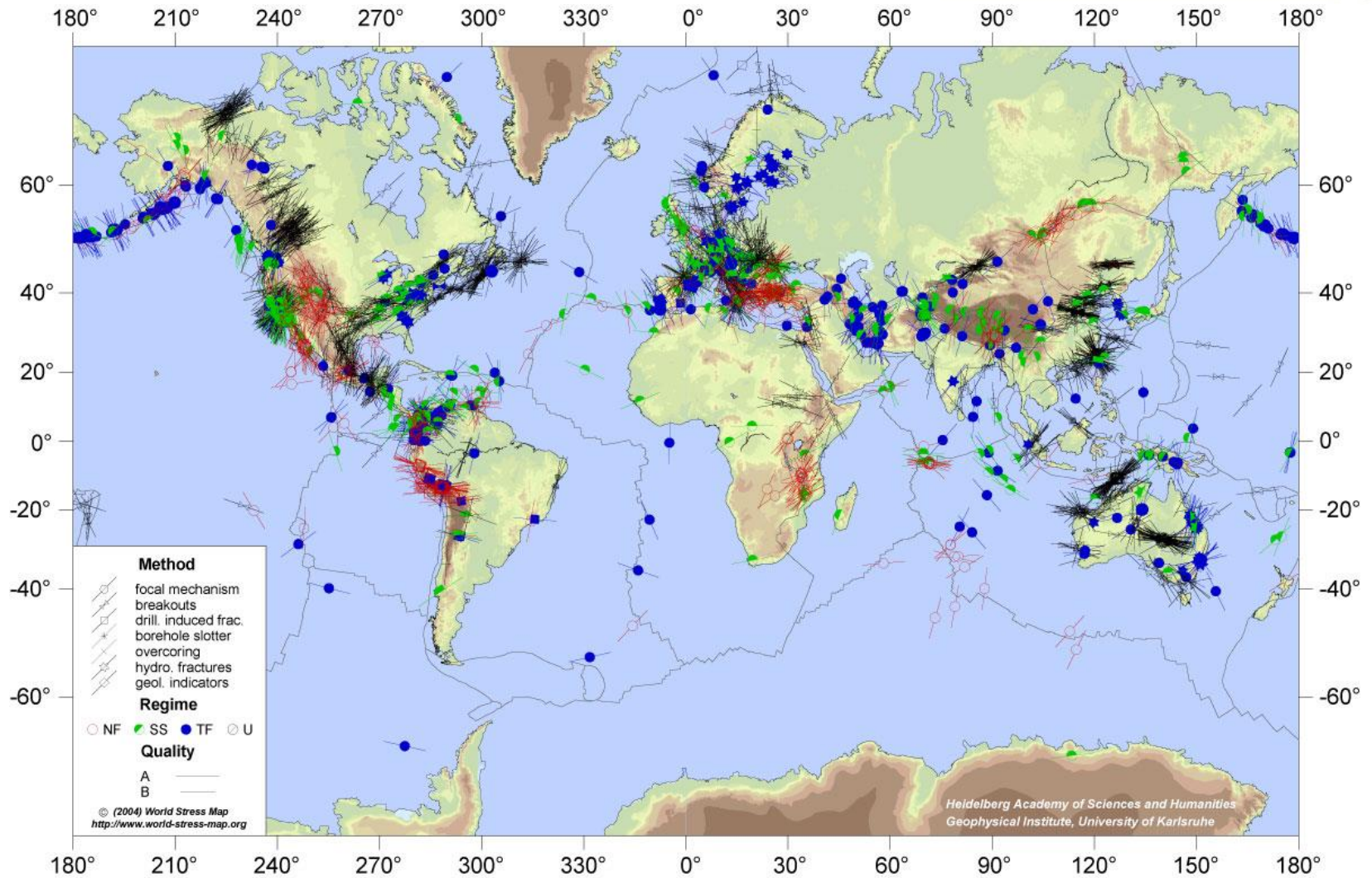
Relações entre as direções dos esforços principais máximos locais e remotos em relação à direção de uma zona de falha preexistente.



Bem-Avrahan & Zoback (1992)

## Determinando os esforços atuais

# World Stress Map

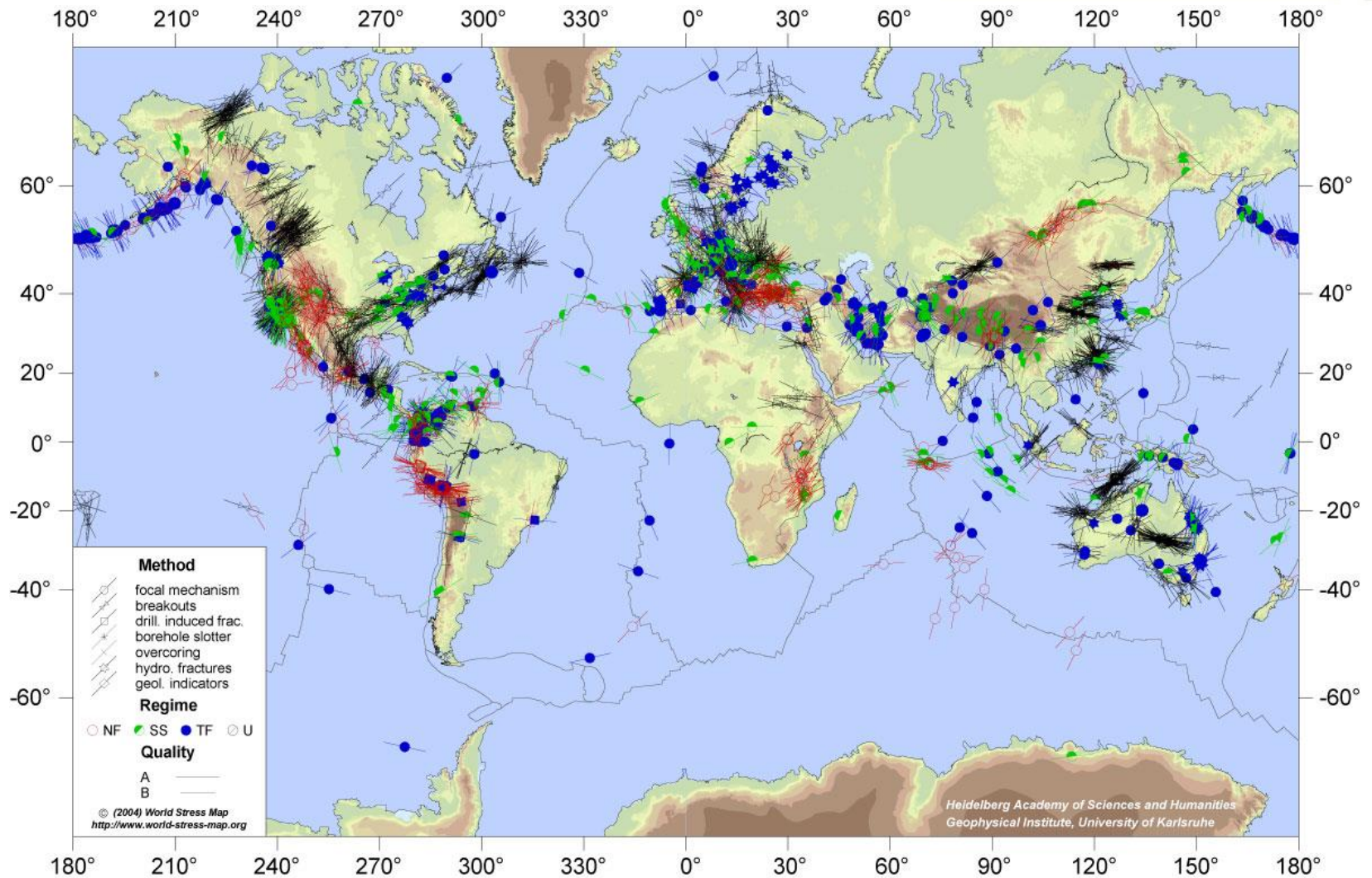


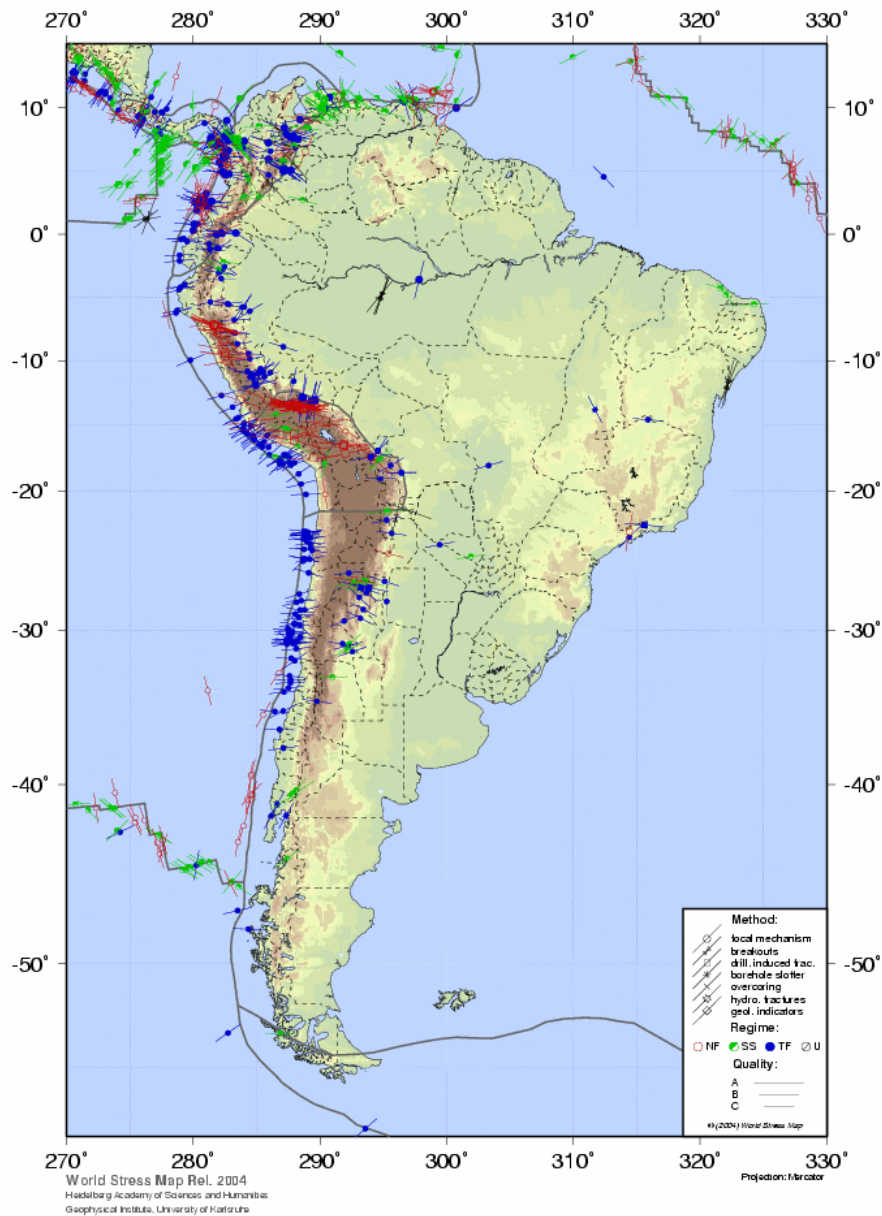


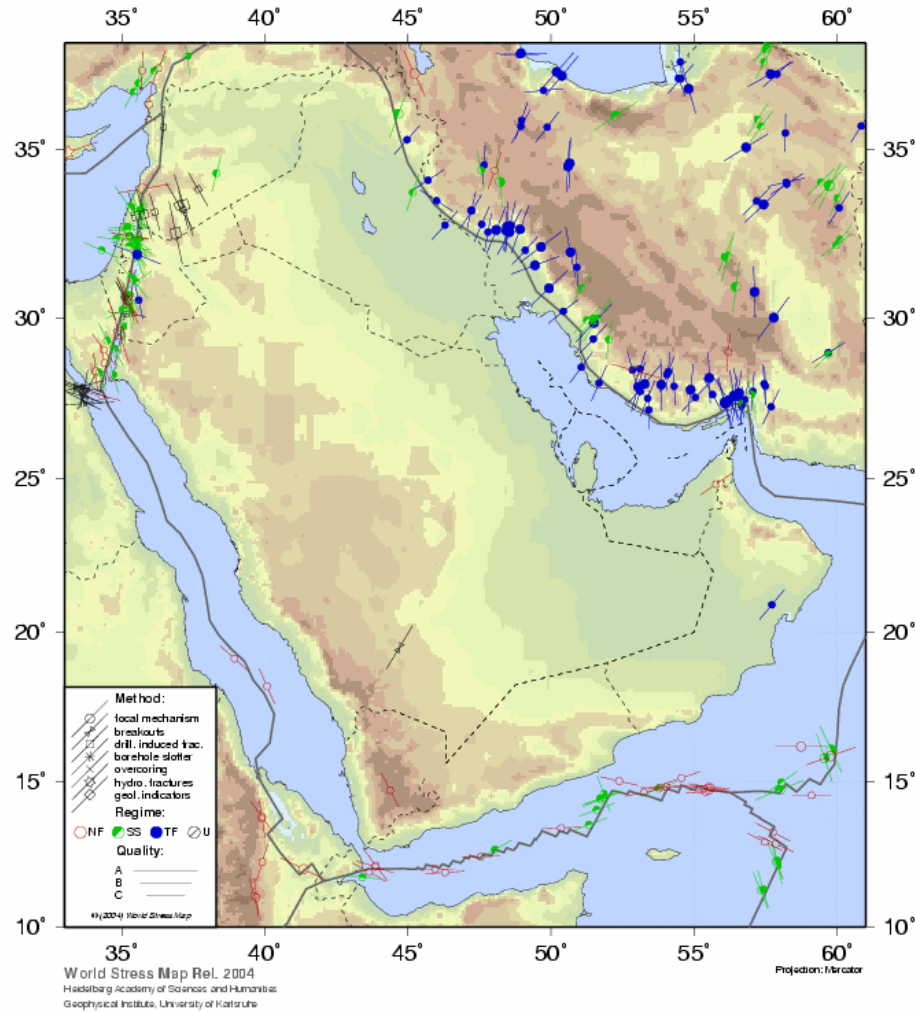
## WSM - aplicações

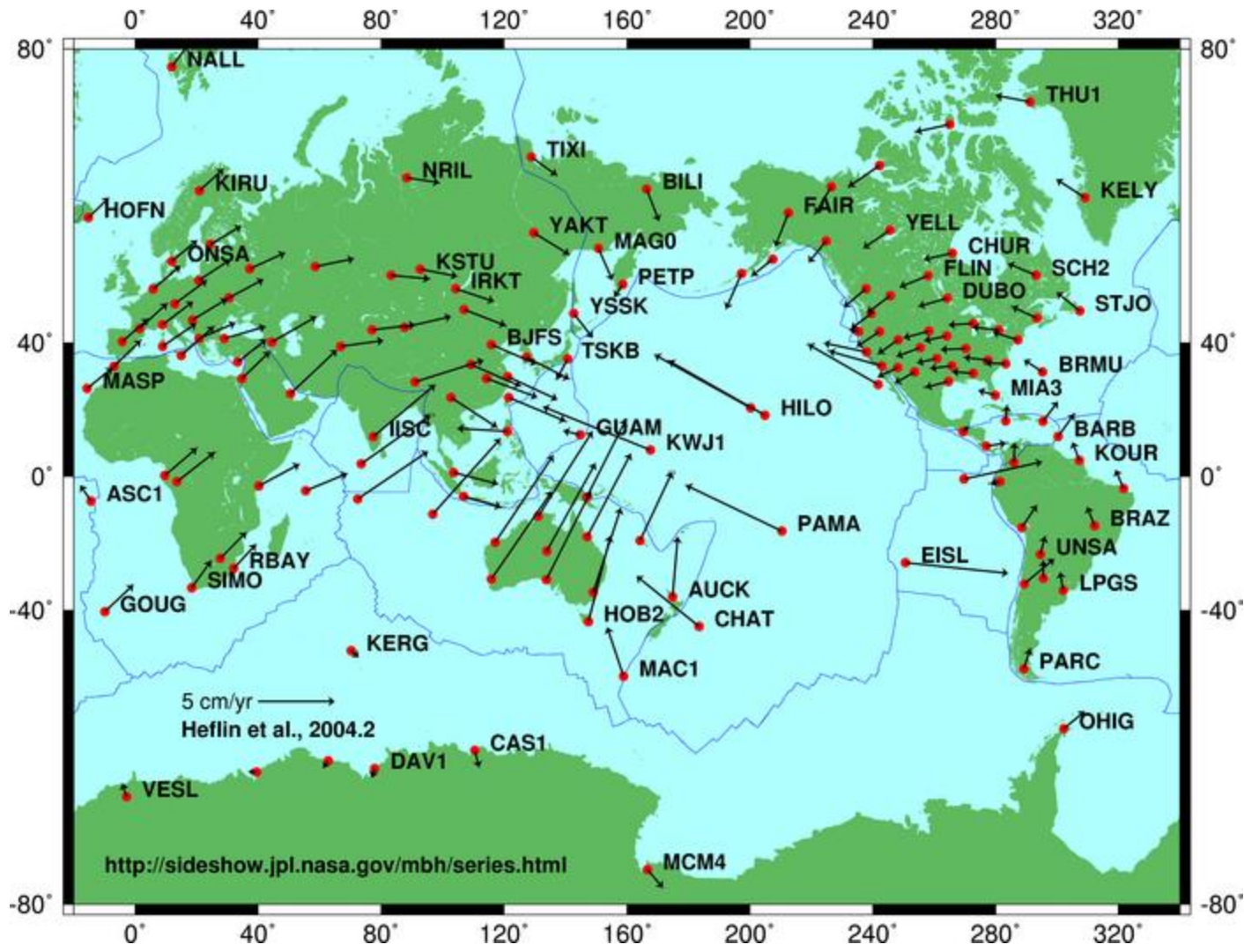
- Modelagem de bacias sedimentares
- Tectônica
- Análise de reservatórios
- Estabilidade de obras de Engenharia
- Avaliação de risco sísmico

# World Stress Map

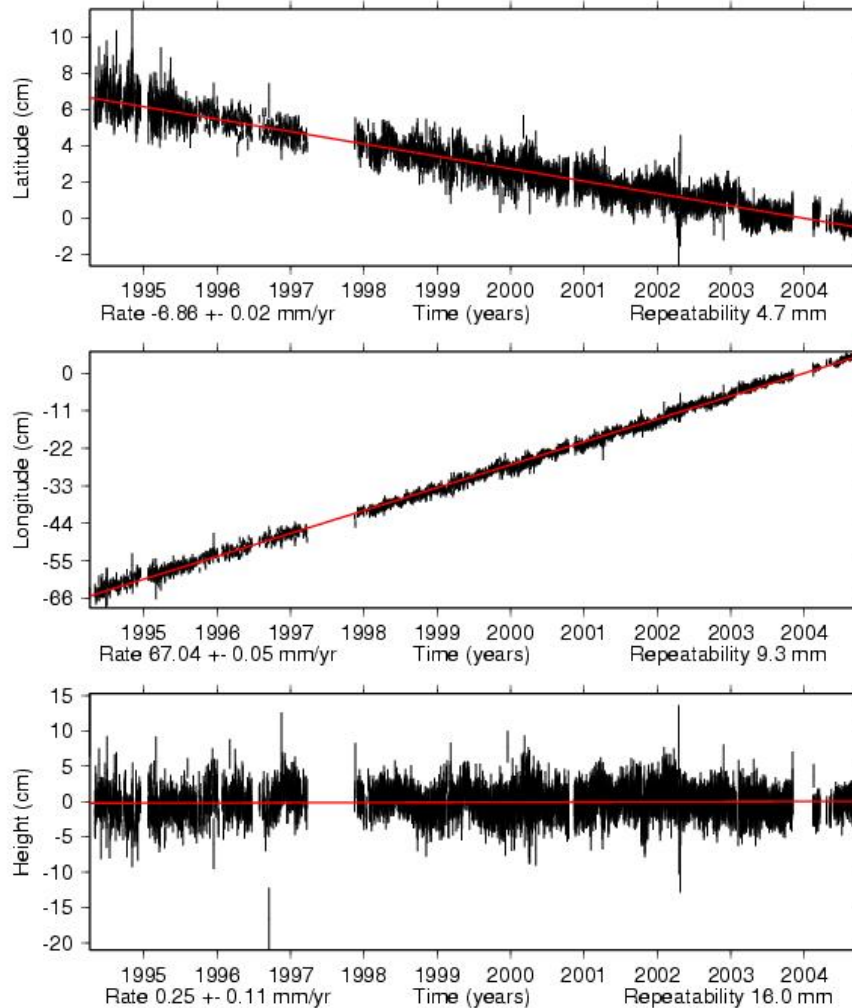


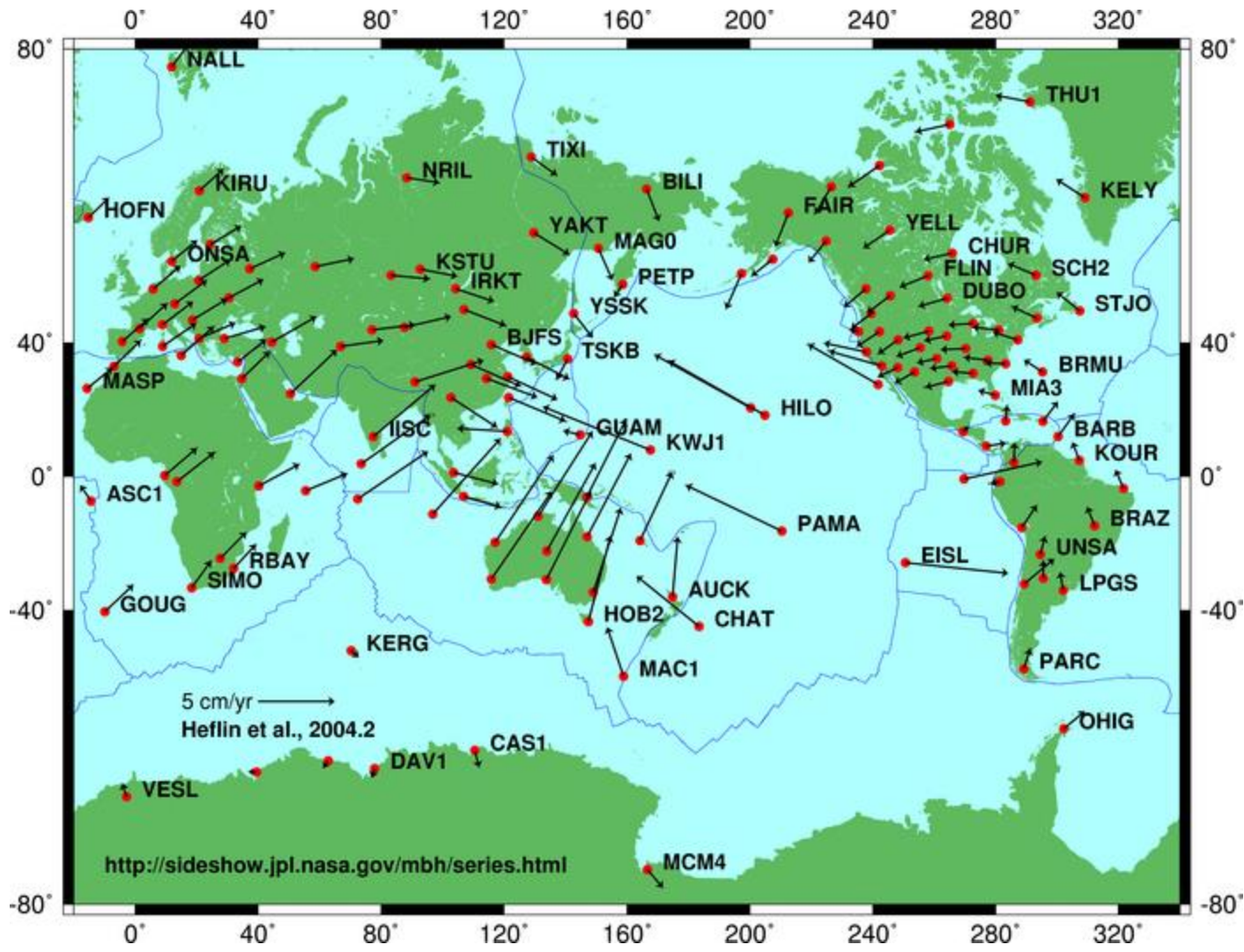




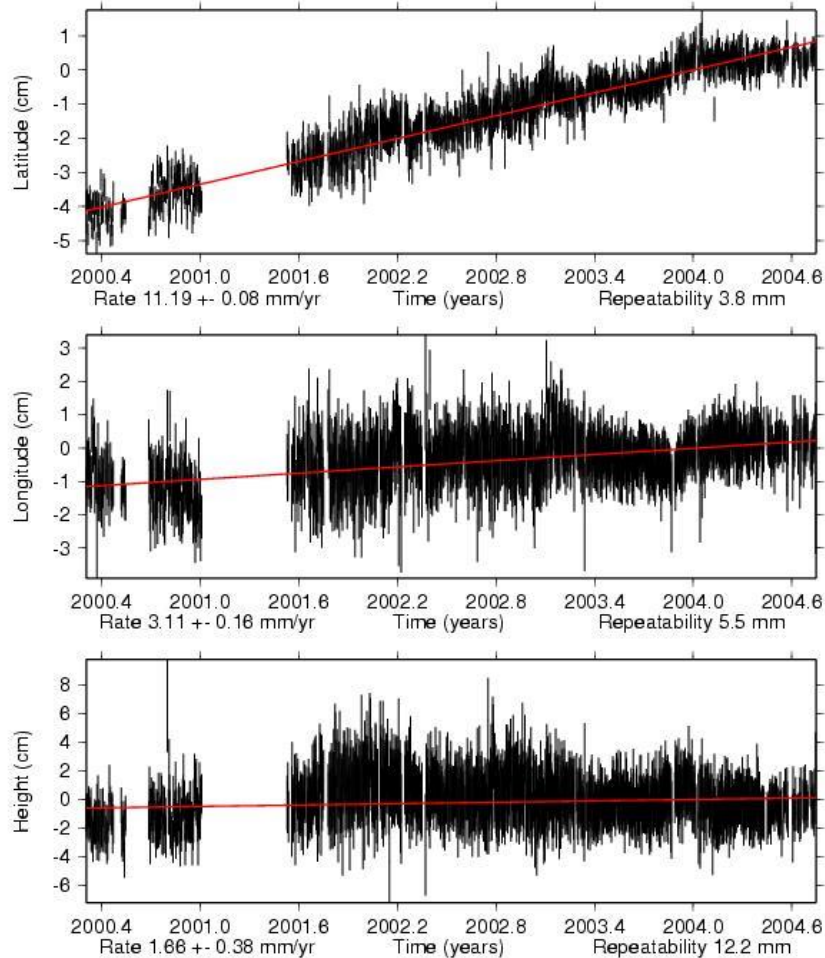


Time series for EISL.

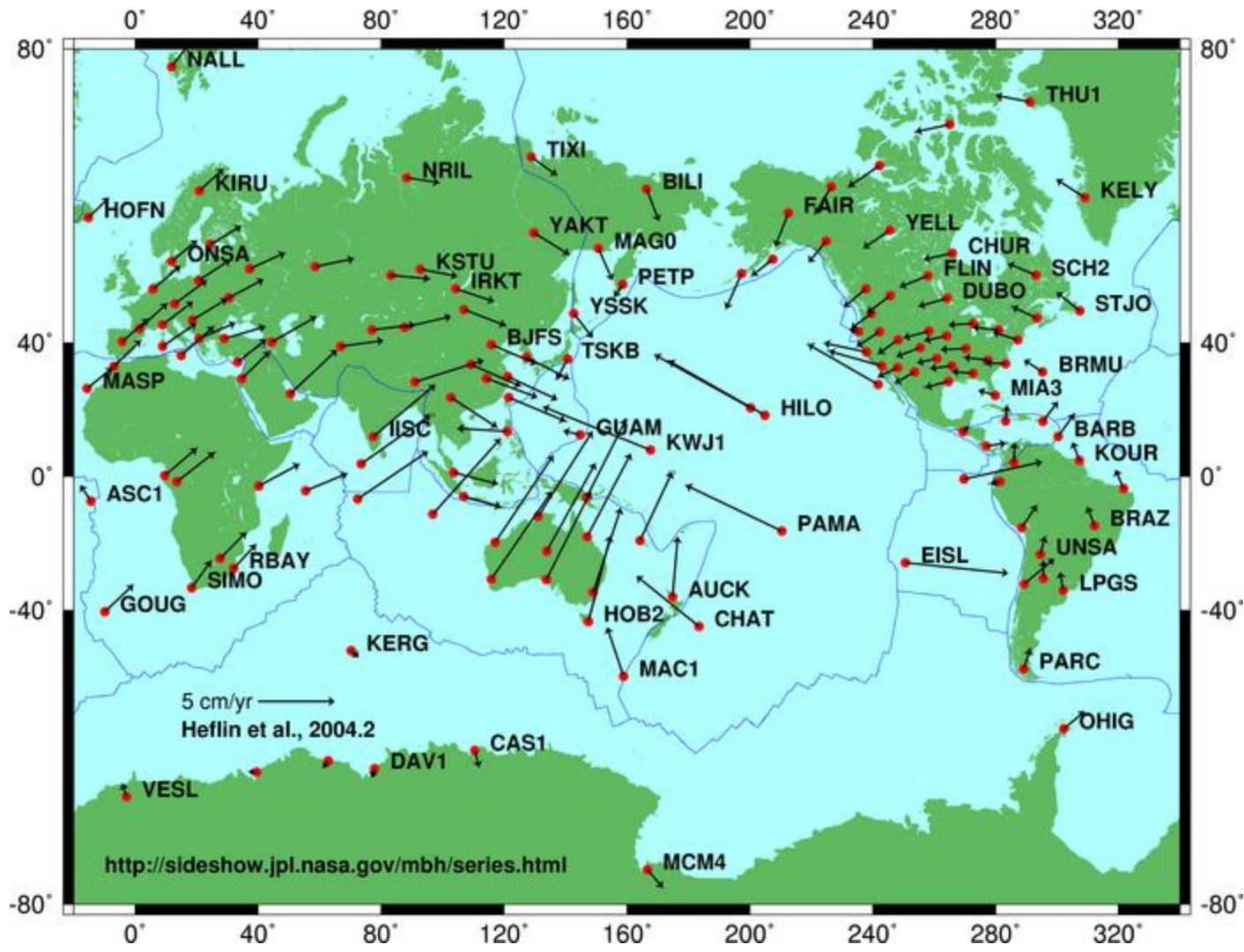




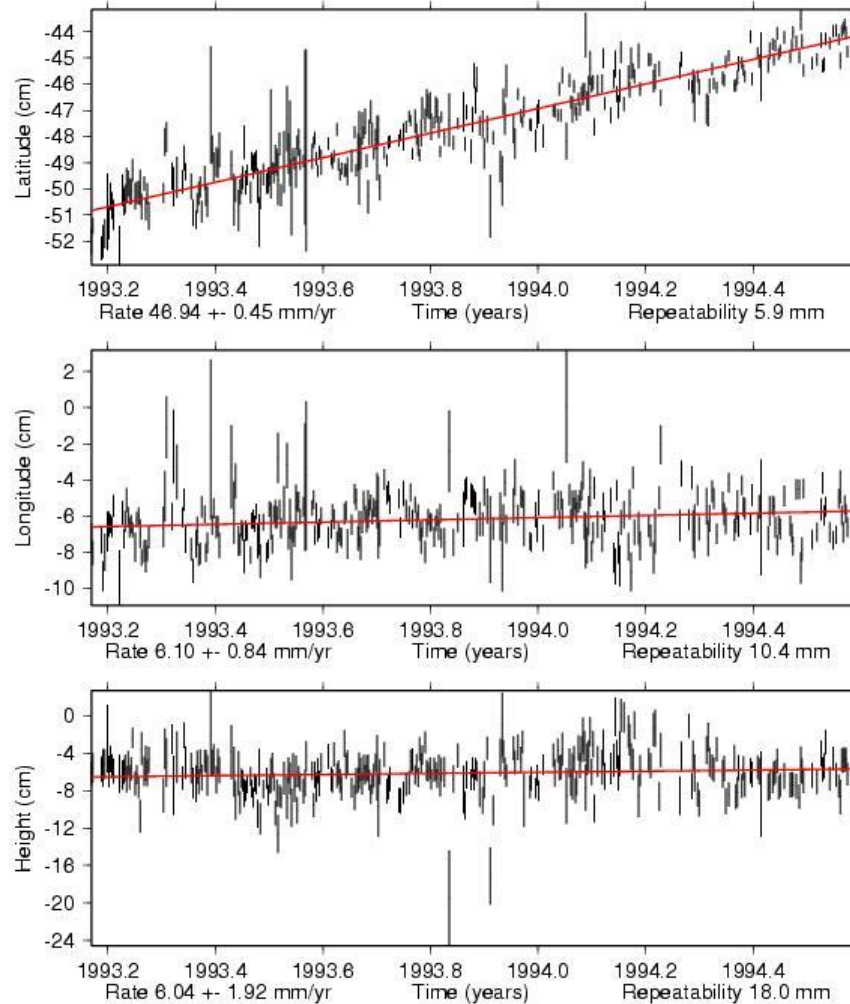
Time series for UNSA.







Time series for HOBA.





## Interseismic strain accumulation measured by GPS in the seismic gap between Constitución and Concepción in Chile

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### ABSTRACT

The Concepción–Constitución area [35–37°S] in South Central Chile is very likely a mature seismic gap, since no large subduction earthquake has occurred there since 1835. Three campaigns of global positioning system (GPS) measurements were carried out in this area in 1996, 1999 and 2002. We observed a network of about 40 sites, including two east–west transects ranging from the coastal area to the Argentina border and one north–south profile along the coast. Our measurements are consistent with the Nazca/South America relative angular velocity (55.9°N, 95.2°W, 0.610°/Ma) discussed by Vigny et al. (2008, this issue) which predicts a convergence of 68 mm/year oriented 79°N at the Chilean trench near 36°S. With respect to stable South America, horizontal velocities decrease from 45 mm/year on the coast to 10 mm/year in the Cordillera. Vertical velocities exhibit a coherent pattern with negative values of about 10 mm/year on the coast and slightly positive or near zero in the Central Valley or the Cordillera. Horizontal velocities have formal uncertainties in the range of 1–3 mm/year and vertical velocities around 3–6 mm/year. Surface deformation in this area of South Central Chile is consistent with a fully coupled elastic loading on the subduction interface at depth. The best fit to our data is obtained with a dip of  $16 \pm 3^\circ$ , a locking depth of  $55 \pm 5$  km and a dislocation corresponding to 67 mm/year oriented 78°N. However in the northern area of our network the fit is improved locally by using a lower dip around 13°. Finally a convergence motion of about 68 mm/year represents more than 10 m of displacement accumulated since the last big interplate subduction event in this area over 170 years ago (1835 earthquake described by Darwin). Therefore, in a worst case scenario, the area already has a potential for an earthquake of magnitude as large as 8–8.5, should it happen in the near future.

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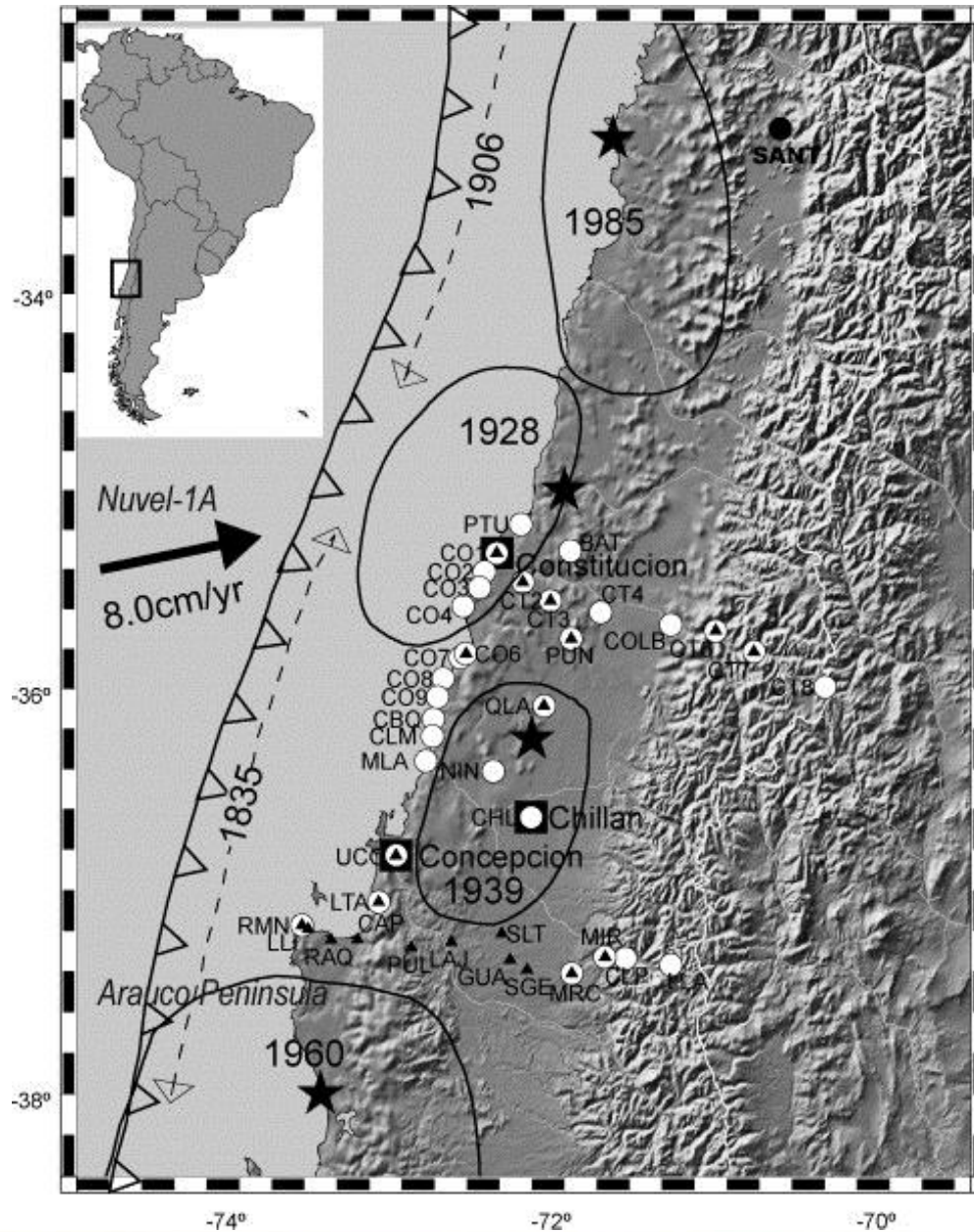
### 1. Introduction

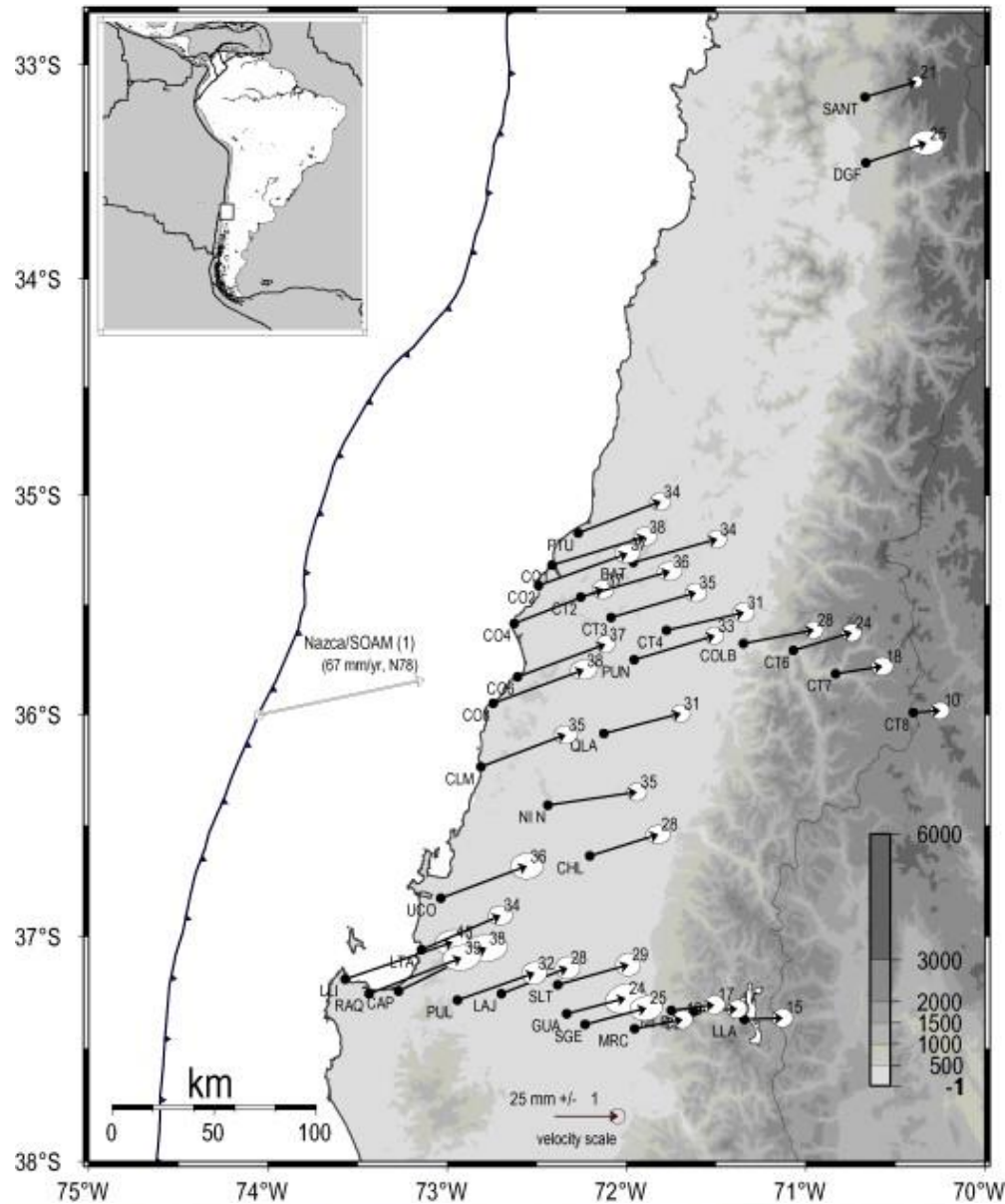
The coastal ranges of Chile are among the most seismically active zones in the world. On average, one major earthquake of magnitude 8 has occurred every 10 years in historical times, and most of the individual segments of the coastal ranges have been the site of at least one magnitude 8 during the last 130 years (Lomnitz, 1971; Kelleher, 1972; Nishenko, 1985). One exception is the South Central Chile region, between 35°S and 37°S, which experienced its last large subduction earthquake on 20 February 1835 (Darwin, 1851) with an estimated magnitude close to 8.5 (Lomnitz, 1971; Beck et al., 1998) (Fig. 1). This area lies immediately to the north of the rupture zone associated with the great 1960 earthquake, of magnitude

9.5 (Plafker and Savage, 1970; Cifuentes, 1989) and south of the rupture zones corresponding to the 1928 Talca earthquake (Beck et al., 1998) and the 1906 and 1985 Valparaíso earthquakes (Barrientos, 1995). Part of the region was affected by the 1939 Chillán earthquake (magnitude 7.9). Recent studies have demonstrated that this event was not a typical subduction earthquake, but was a slab-pull event due to the release of tensional stresses within the downgoing slab (Campos and Kausel, 1990; Beck et al., 1998). Further north, the Talca earthquake of 1 December 1928, was interpreted as a shallow dipping thrust event (Lomnitz, 1971; Beck et al., 1998). Despite the uncertainties that remain on the importance of the 1928 and 1939 earthquakes and their impact on the seismic cycle, the region from 35°S to 37°S is a likely spot for a major subduction earthquake in the coming decades. In any case, it is the longest standing gap in Chile, the better known northern Chile gap was affected by large earthquakes in 1868 and 1877 (Lomnitz, 1971; Kelleher, 1972).

\* Corresponding author.

E-mail address: [ruegg@ipgp.jussieu.fr](mailto:ruegg@ipgp.jussieu.fr) (J.C. Ruegg).





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## A B S T R A C T

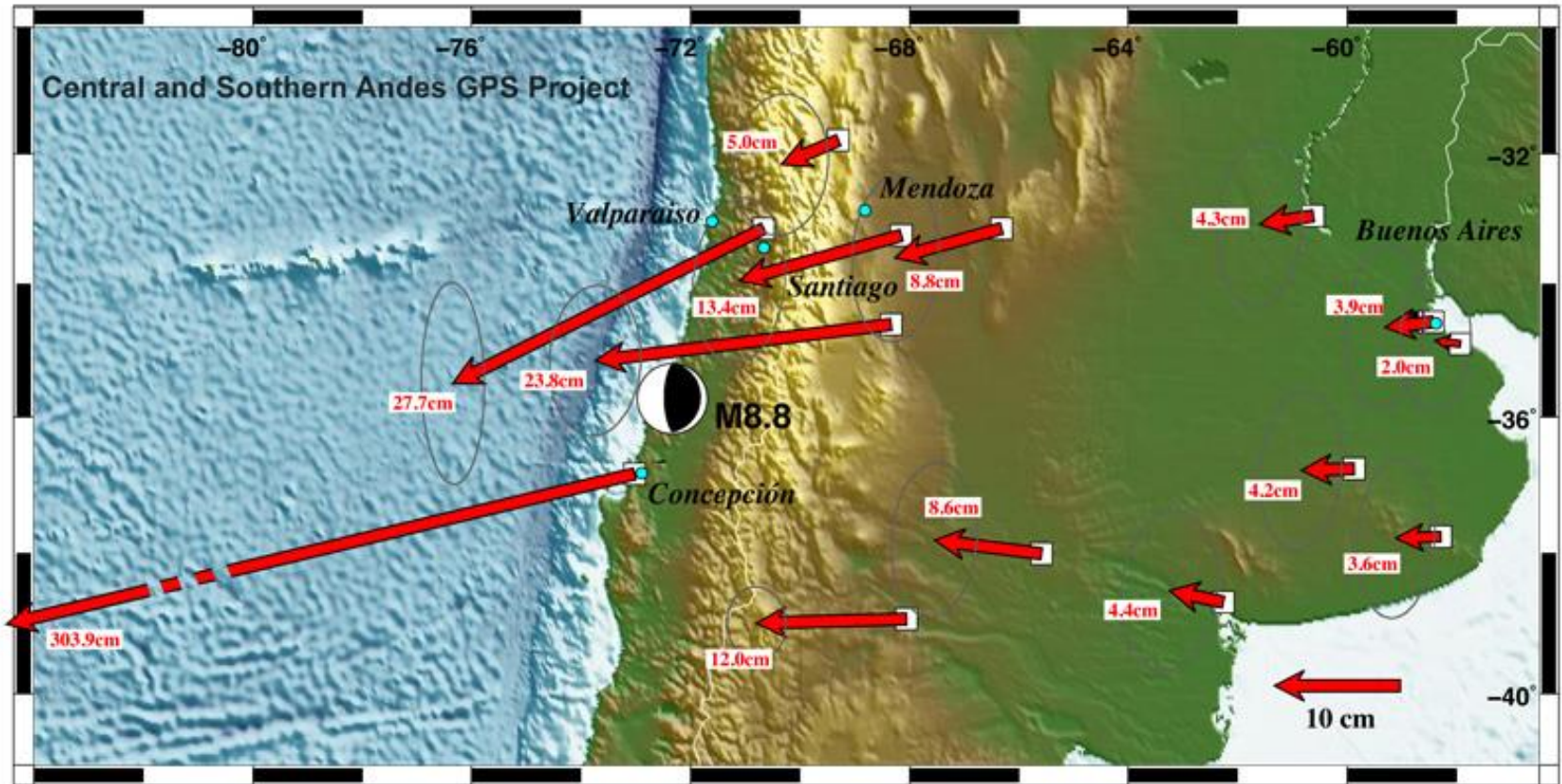
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The Concepción–Constitución area [35–37°S] in South Central Chile is very likely a mature seismic gap, since no large subduction earthquake has occurred there since 1835. Three campaigns of global positioning system (GPS) measurements were carried out in this area in 1996, 1999 and 2002. We observed a network of about 40 sites, including two east–west transects ranging from the coastal area to the Argentina border and one north–south profile along the coast. Our measurements are consistent with the Nazca/South America relative angular velocity (55.9°N, 95.2°W, 0.610°/Ma) discussed by Vigny et al. (2008, this issue) which predicts a convergence of 68 mm/year oriented 79°N at the Chilean trench near 36°S. With respect to stable South America, horizontal velocities decrease from 45 mm/year on the coast to 10 mm/year in the Cordillera. Vertical velocities exhibit a coherent pattern with negative values of about 10 mm/year on the coast and slightly positive or near zero in the Central Valley or the Cordillera. Horizontal velocities have formal uncertainties in the range of 1–3 mm/year and vertical velocities around 3–6 mm/year. Surface deformation in this area of South Central Chile is consistent with a fully coupled elastic loading on the subduction interface at depth. The best fit to our data is obtained with a dip of  $16 \pm 3^\circ$ , a locking depth of  $55 \pm 5$  km and a dislocation corresponding to 67 mm/year oriented 78°N. However in the northern area of our network the fit is improved locally by using a lower dip around 13°. Finally a convergence motion of about 68 mm/year represents more than 10 m of displacement accumulated since the last big interplate subduction event in this area over 170 years ago (1835 earthquake described by Darwin). Therefore, in a worst case scenario, the area already has a potential for an earthquake of magnitude as large as 8–8.5, should it happen in the near future.

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9.5 (Plafker and Savage, 1970; Cifuentes, 1989) and south of the rupture zones corresponding to the 1928 Talca earthquake (Beck et al., 1998) and the 1906 and 1985 Valparaiso earthquakes (Barrientos,







# Estruturas em afloramentos

- estruturas comuns: juntas, falhas com estrias, dobras;

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- obtenção de atitudes de estruturas planares e lineares;

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- notação de dados estruturais;

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- obtenção de atitudes de estruturas planares e lineares;
- notação de dados estruturais;
- projeção estereográfica;

- estruturas comuns: juntas, falhas com estrias, dobras;
- obtenção de atitudes de estruturas planares e lineares;
- notação de dados estruturais;
- projeção estereográfica;
- determinação de paleoesforços.

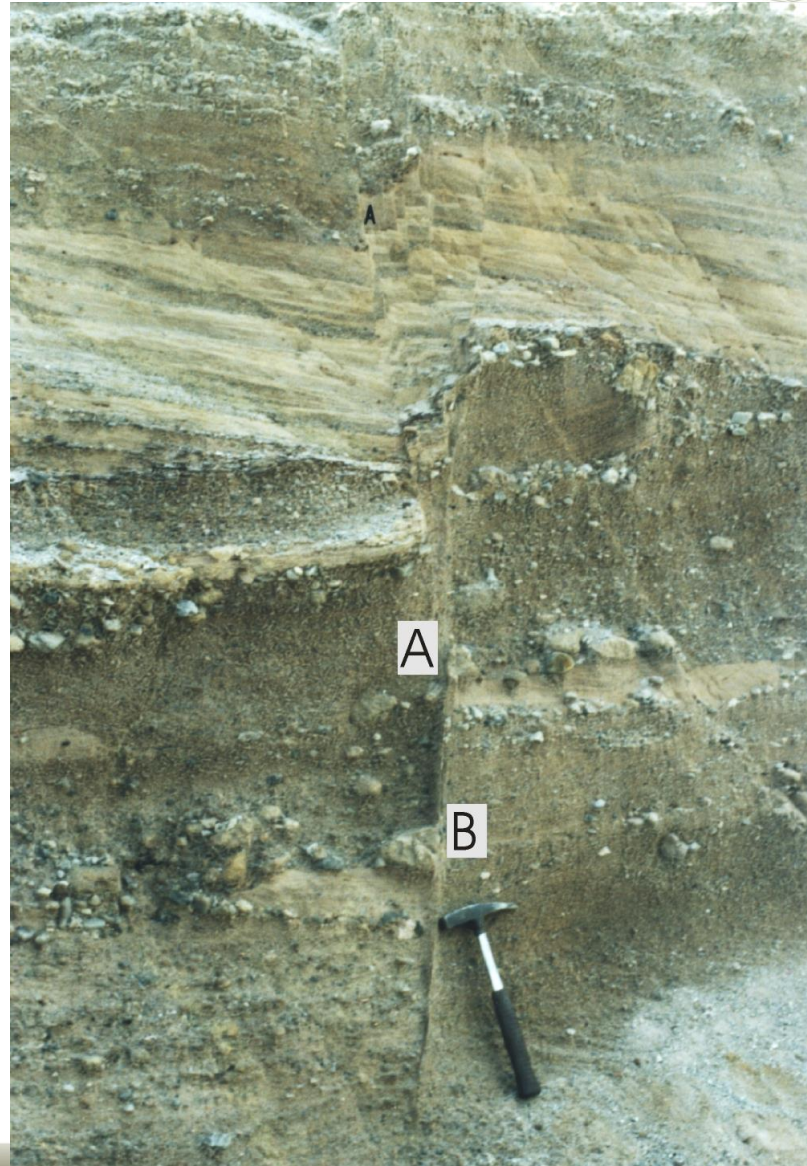
- estruturas comuns: juntas, falhas com estrias, dobras;



juntas

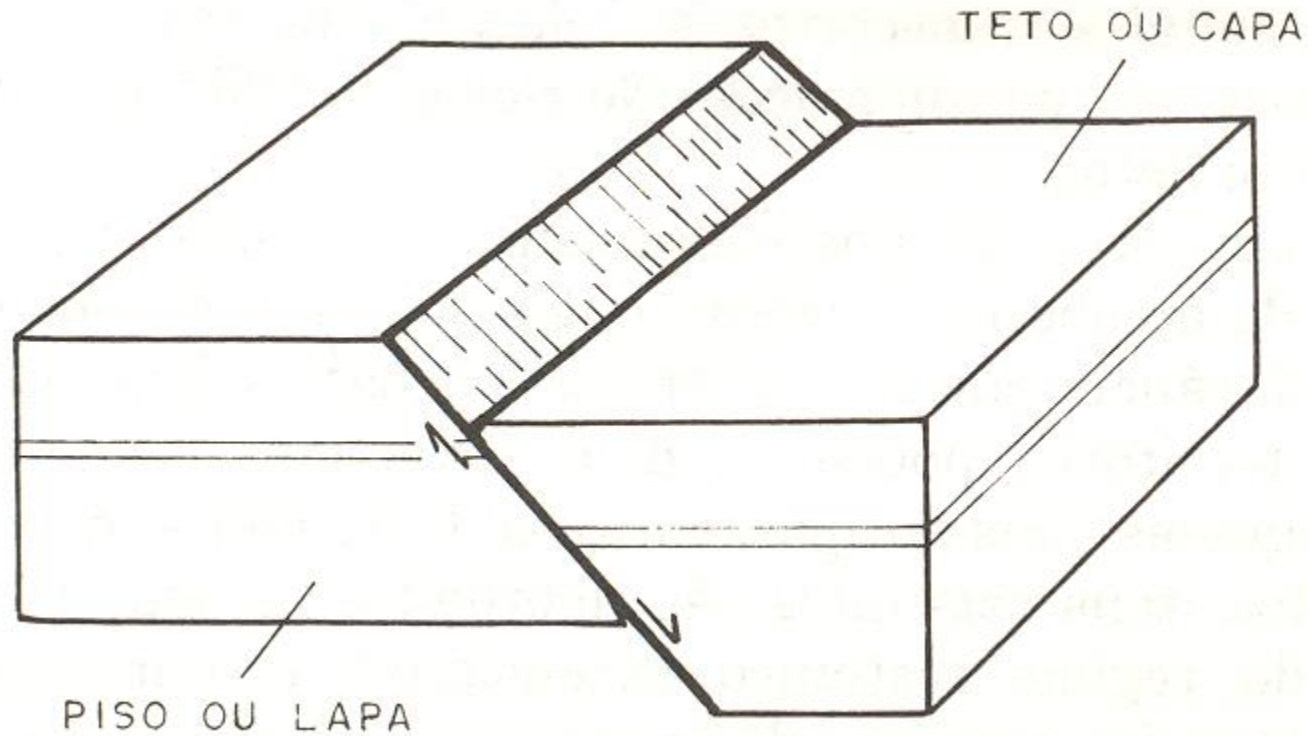








## Elementos de uma falha



# Componentes do rejeito de uma falha normal

R - Rejeito total

d - Rejeito direcional

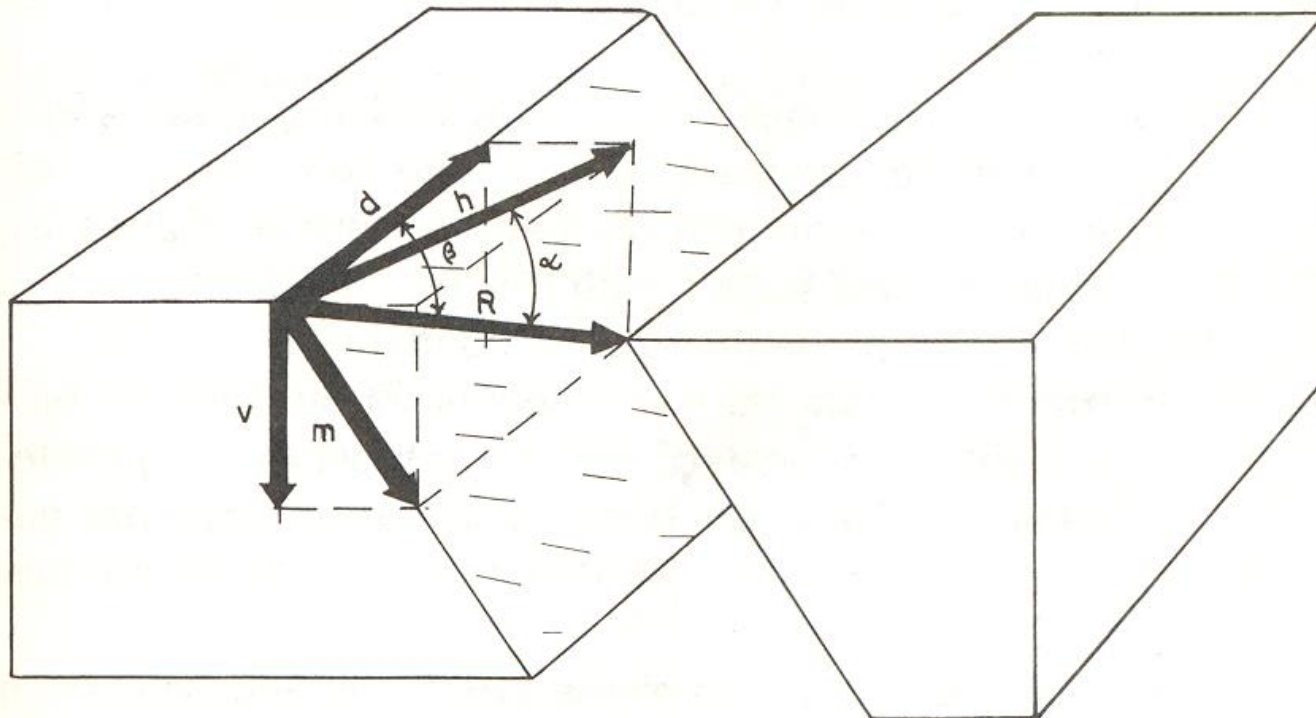
m - Rejeito de mergulho

h - Rejeito horizontal

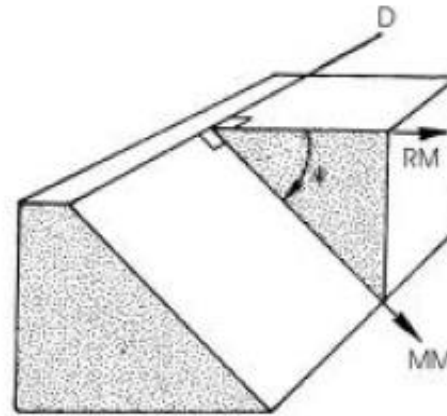
v - Rejeito vertical

$\alpha$  - mergulho do rejeito

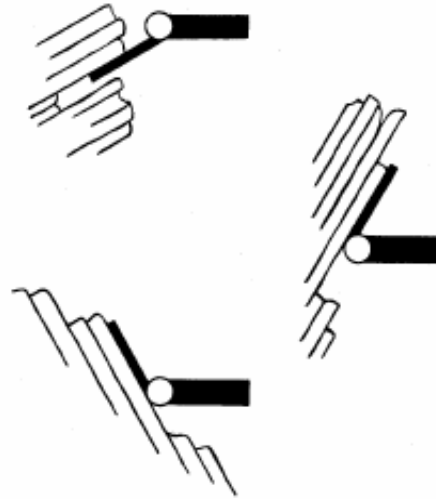
$\beta$  - inclinação do rejeito



- estruturas comuns: juntas, falhas com estrias, dobras;
- obtenção de atitudes de estruturas planares e lineares;

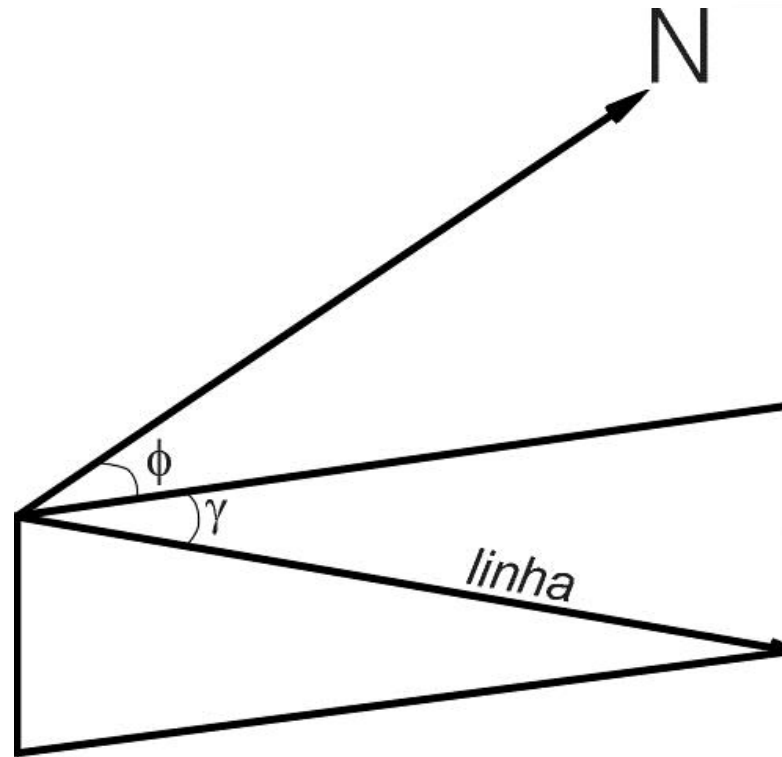


Elementos básicos de uma estrutura planar



Uso da bússola Clar para tomada de atitudes de estruturas planares

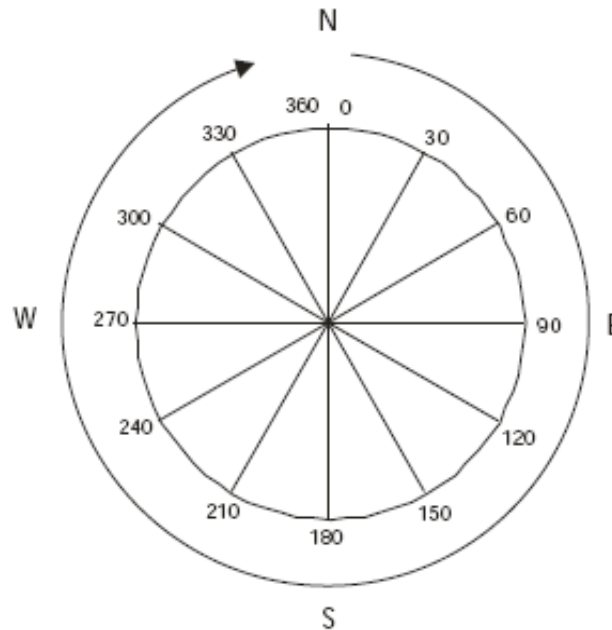




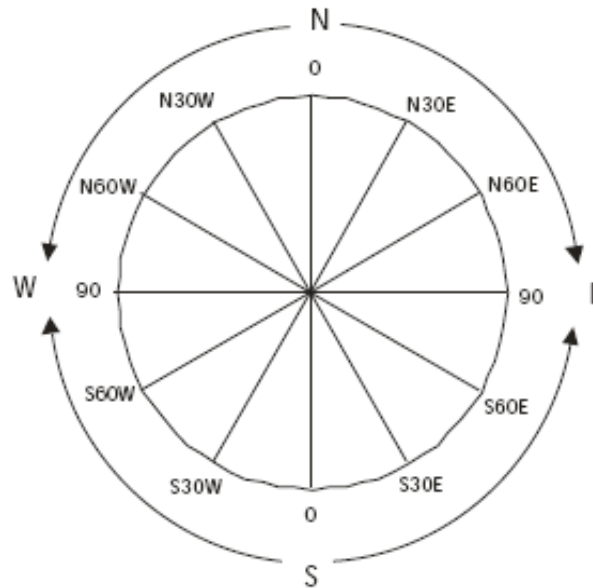
$\phi$  - rumo do mergulho  
 $\gamma$  - ângulo de caimento

Elementos geométricos na definição de atitude de uma linha

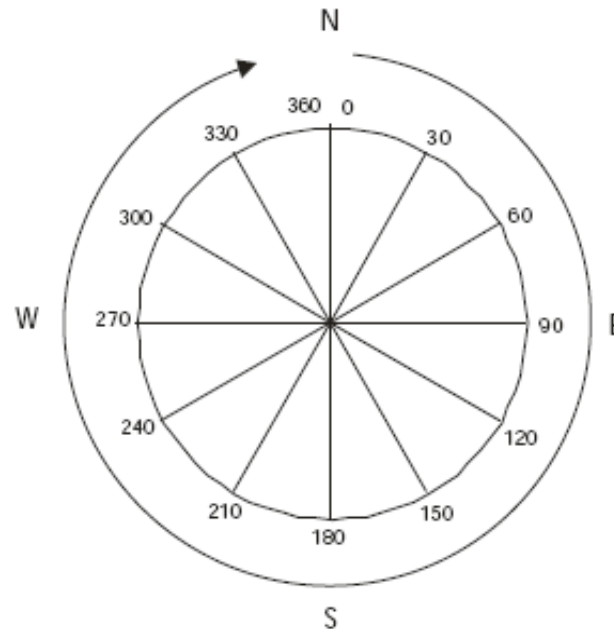
- estruturas comuns: juntas, falhas com estrias, dobras;
- obtenção de atitudes de estruturas planares e lineares;
- **notação de dados estruturais;**



Notação azimutal: N030/60SE; N205/50NW



Notação por quadrante - N30W; N45E



Notação por rumo de mergulho: 240/60; 105/48.

# Estrias em superfície de falha



# Estrias em superfície de falha



Notação de dados pareados (falha e estria):



068/45//068/45 -  
estria coincide com o rumo  
do mergulho;

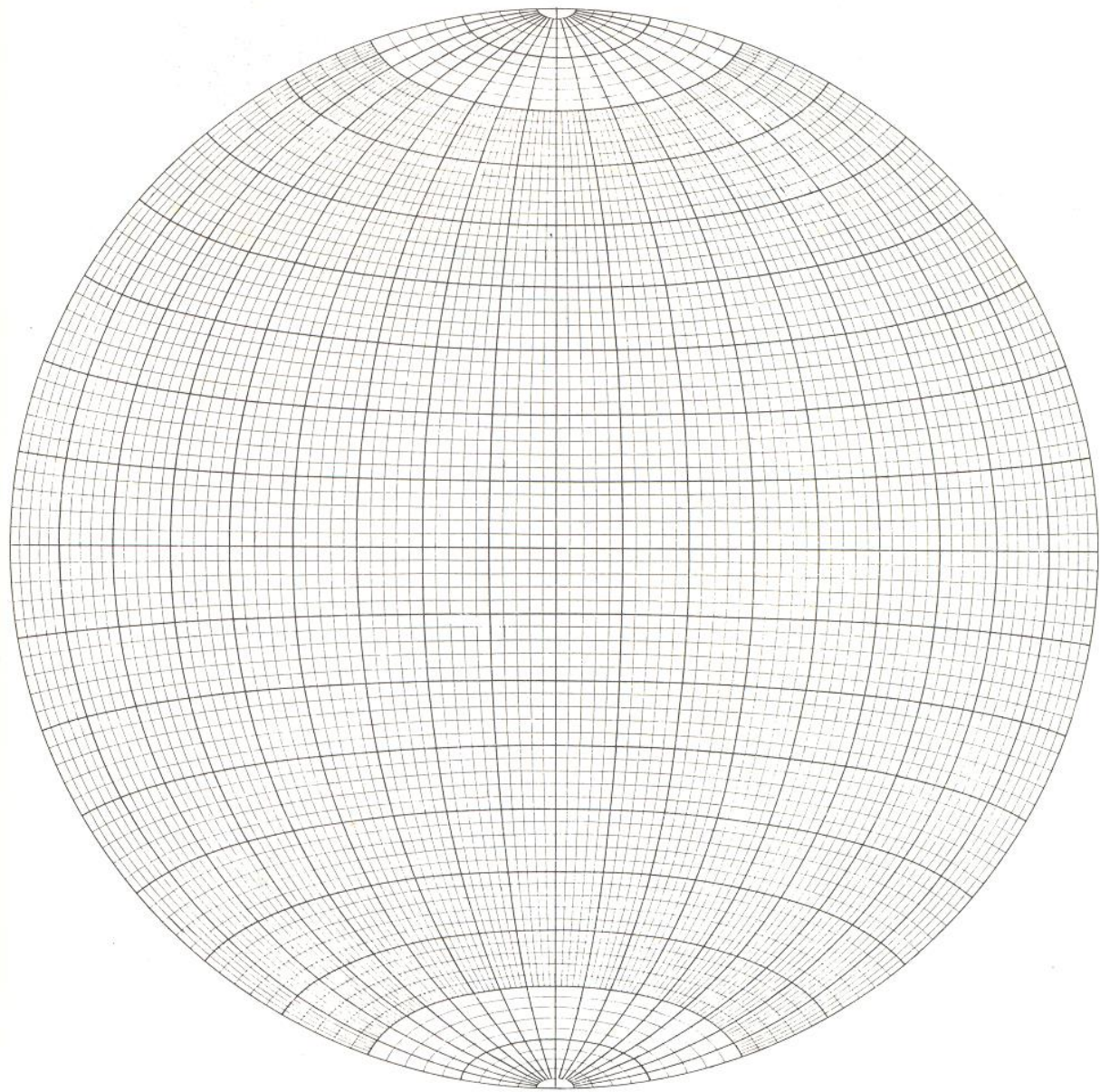
348/65//305/32 -  
estria com obliquidade.

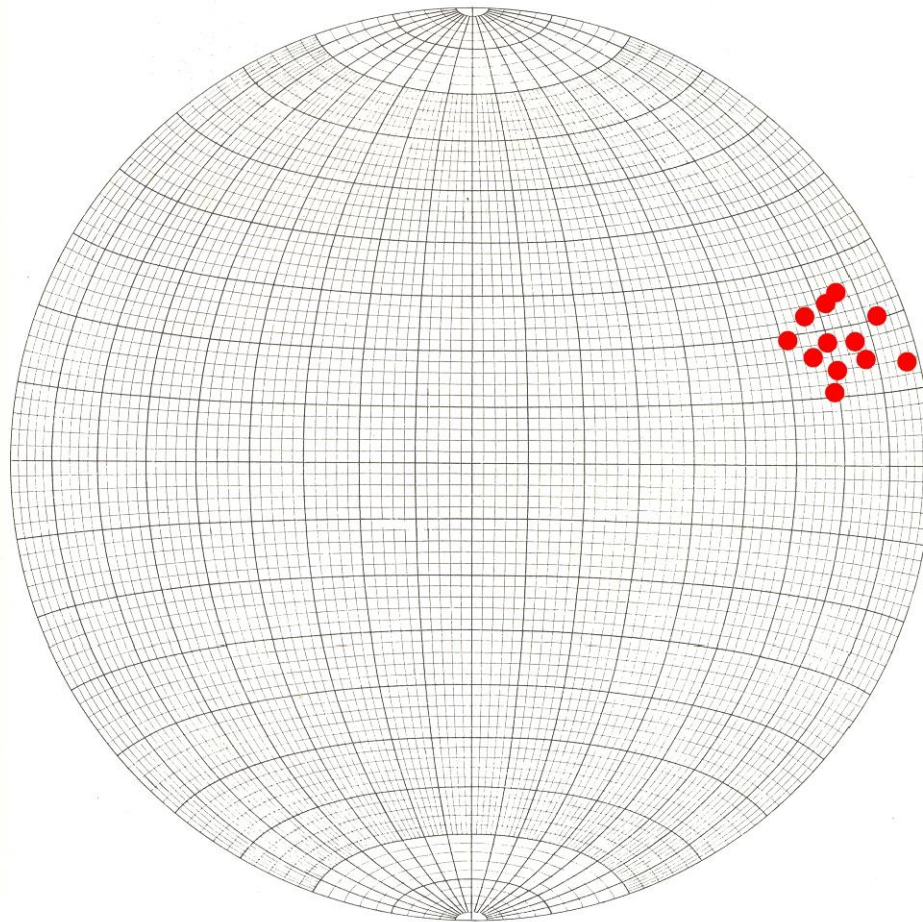




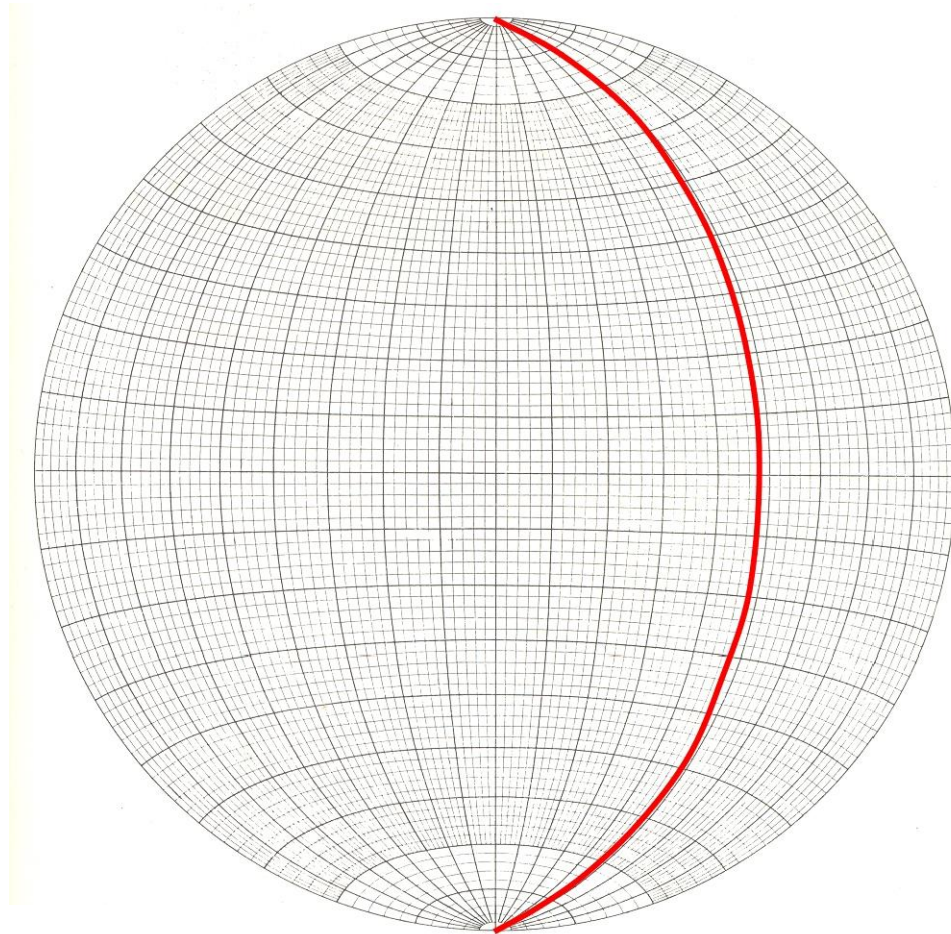
- estruturas comuns: juntas, falhas com estrias, dobras;
- obtenção de atitudes de estruturas planares e lineares;
- notação de dados estruturais;

- estruturas comuns: juntas, falhas com estrias, dobras;
- obtenção de atitudes de estruturas planares e lineares;
- notação de dados estruturais;
- **projeção estereográfica;**

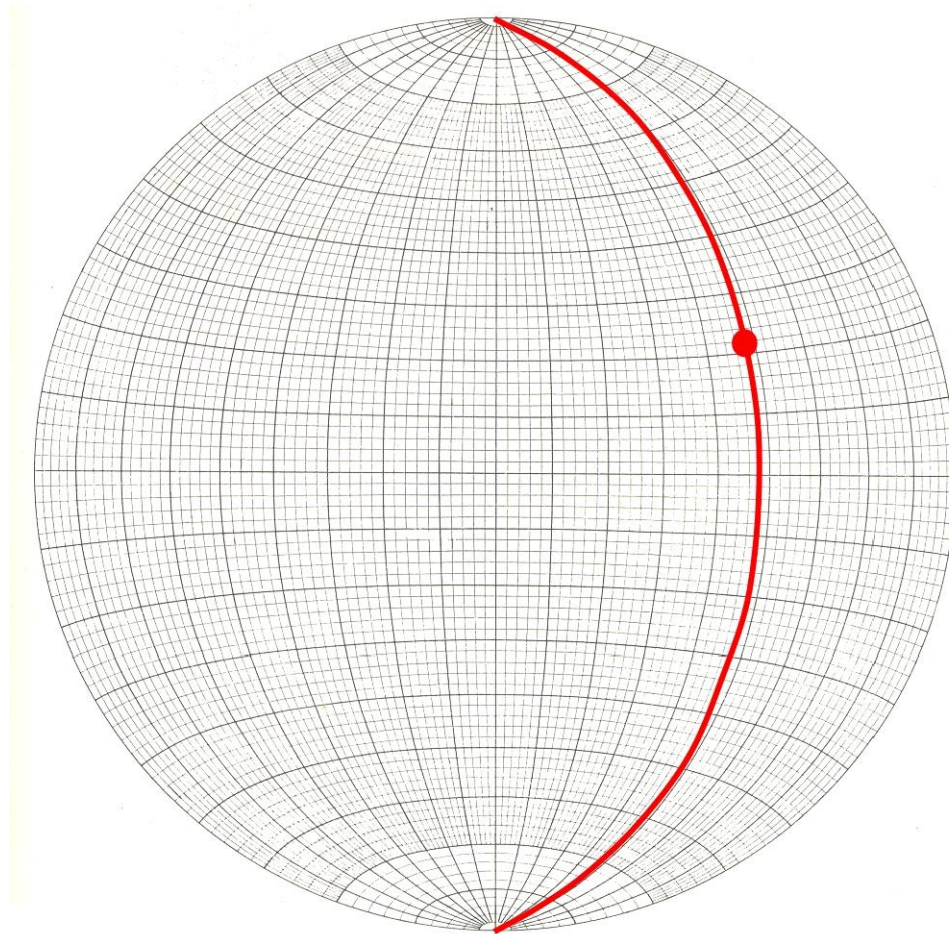




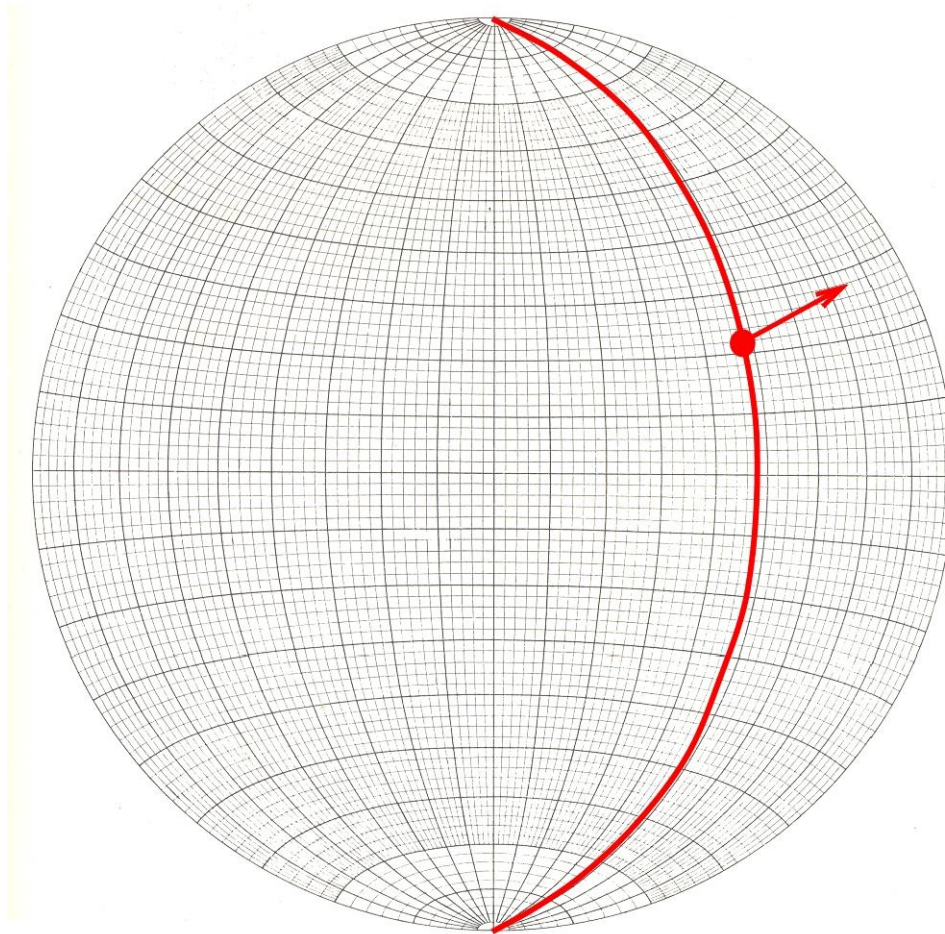
Projeção polar de estruturas planares (p. ex. juntas)



Projeção ciclográfica de uma estrutura planar



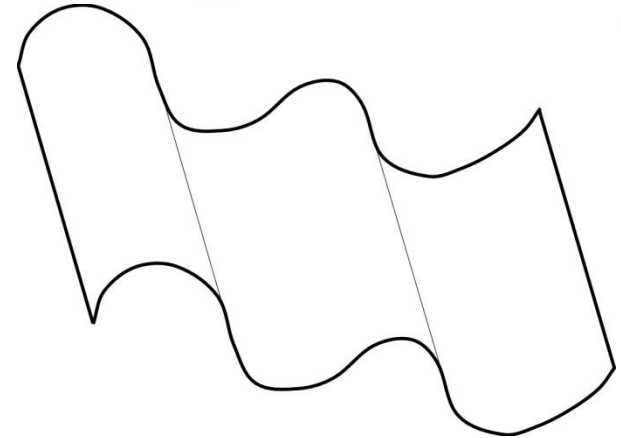
Projeção ciclográfica de uma estrutura planar e uma estrutura linear contida no plano (ex. dado pareado de falha e estria)



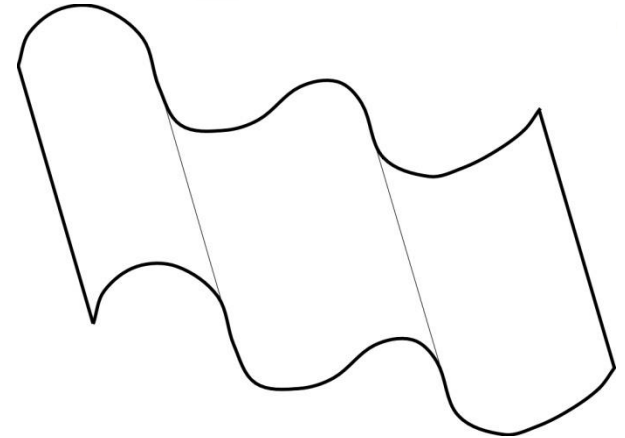
Projeção de uma falha normal com estria oblíqua



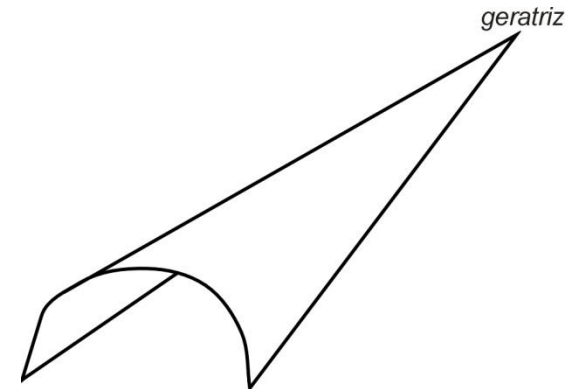




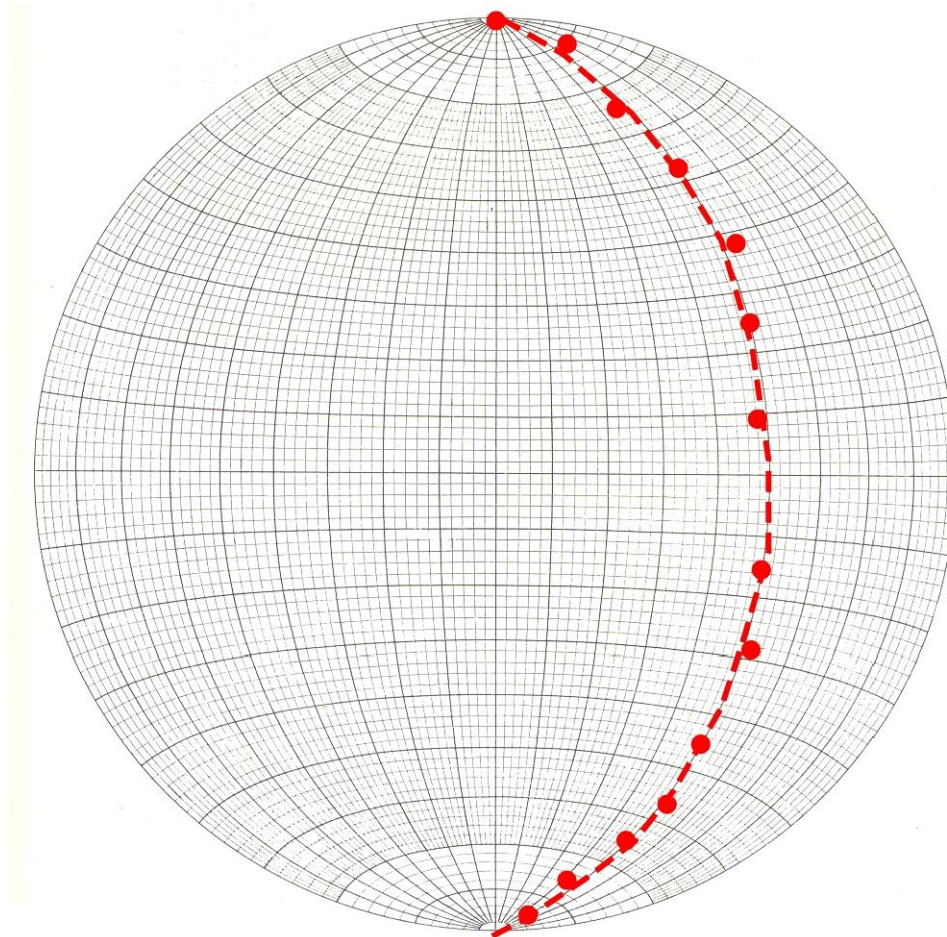
Dobra cilíndrica



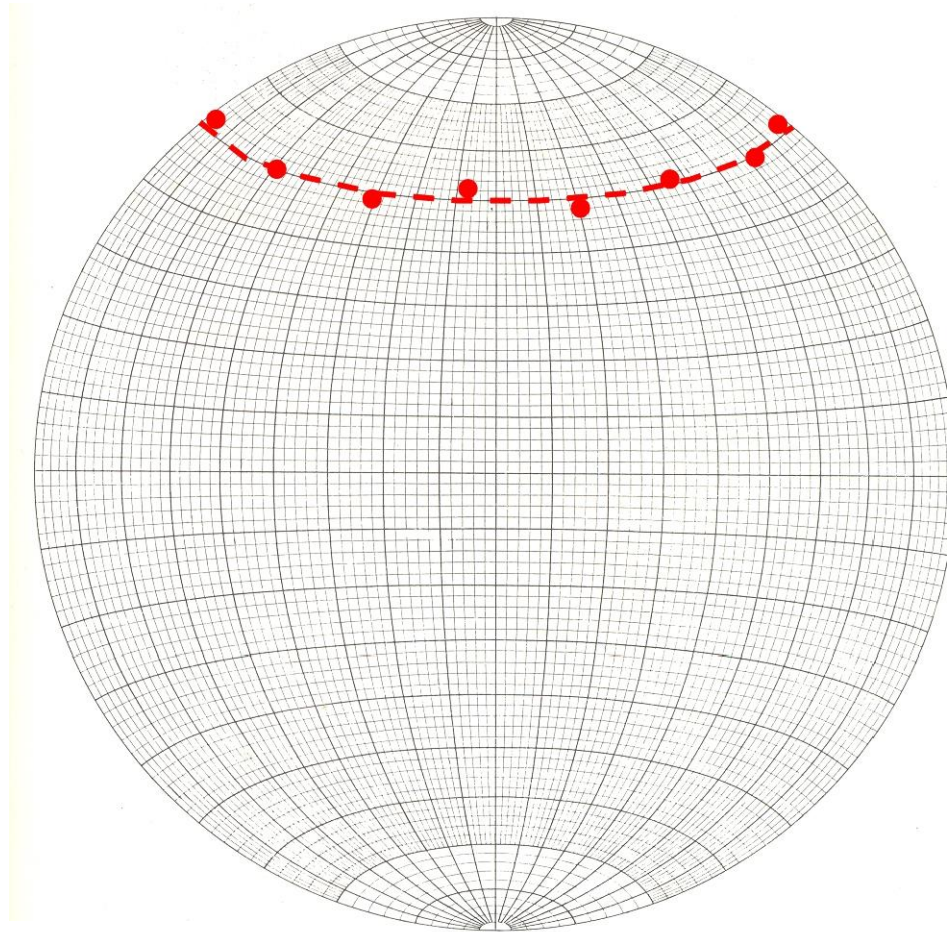
Dobra cilíndrica



Dobra cônica

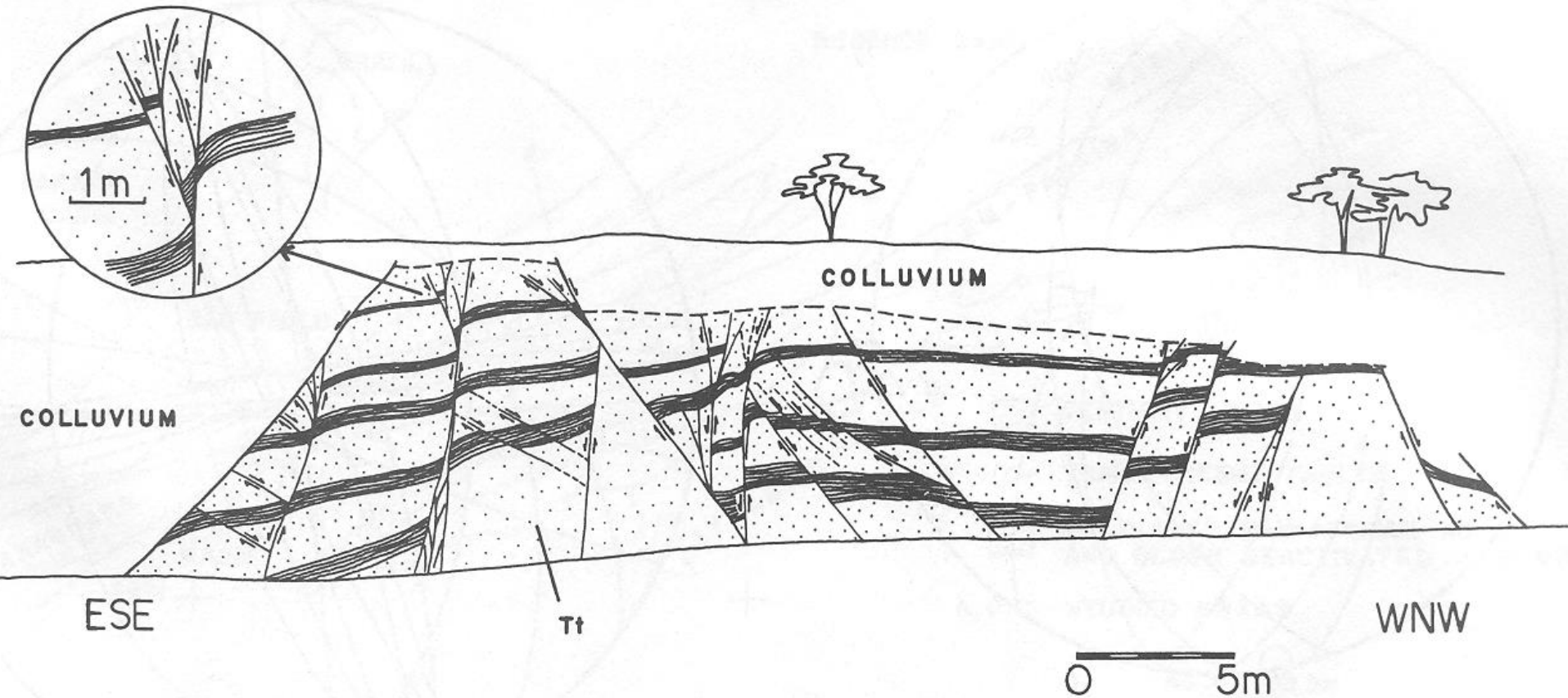


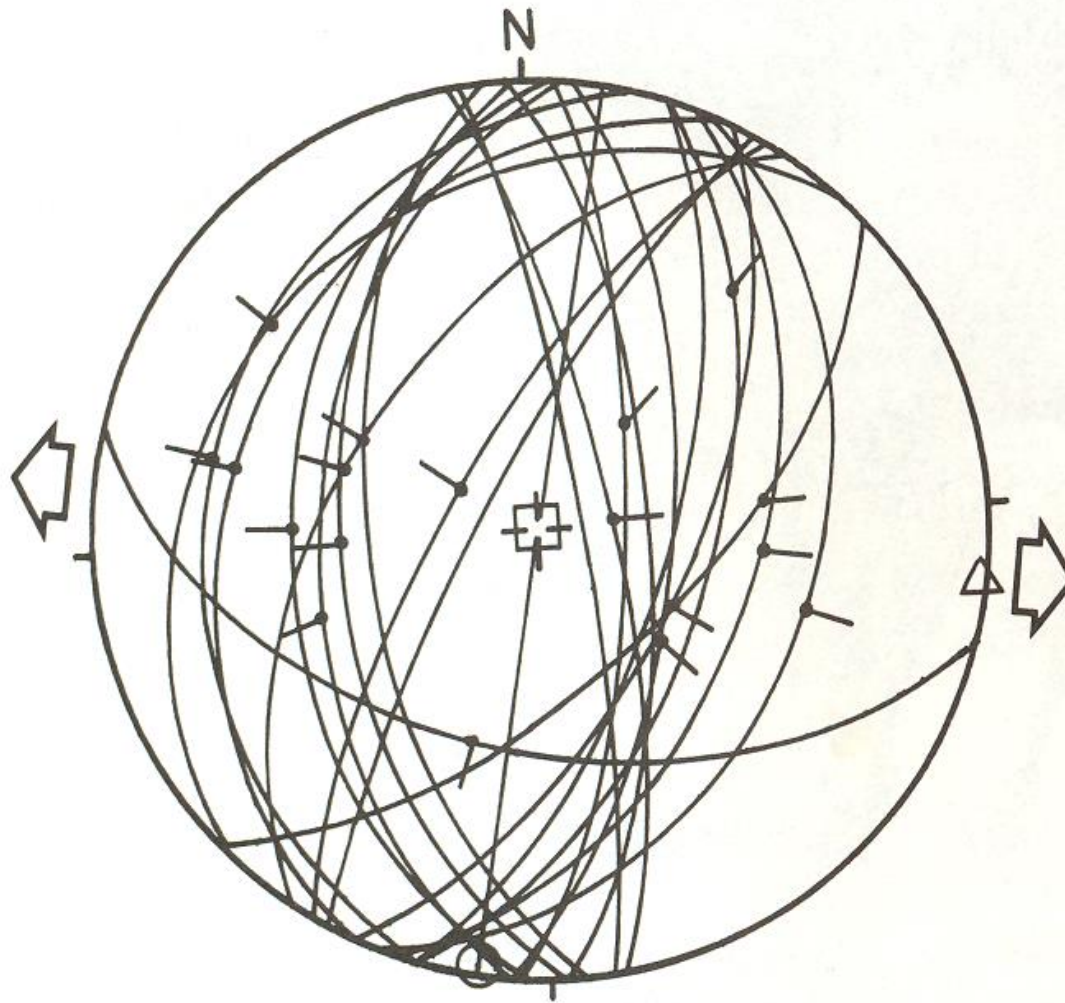
Projeção polar do flanco de uma dobra cilíndrica  
(círculo máximo)



Projeção polar do flanco de uma dobra cônica  
(círculo mínimo)

- estruturas comuns: juntas, falhas com estrias, dobras;
- obtenção de atitudes de estruturas planares e lineares;
- notação de dados estruturais;
- projeção estereográfica;
- **determinação de paleoesforços.**



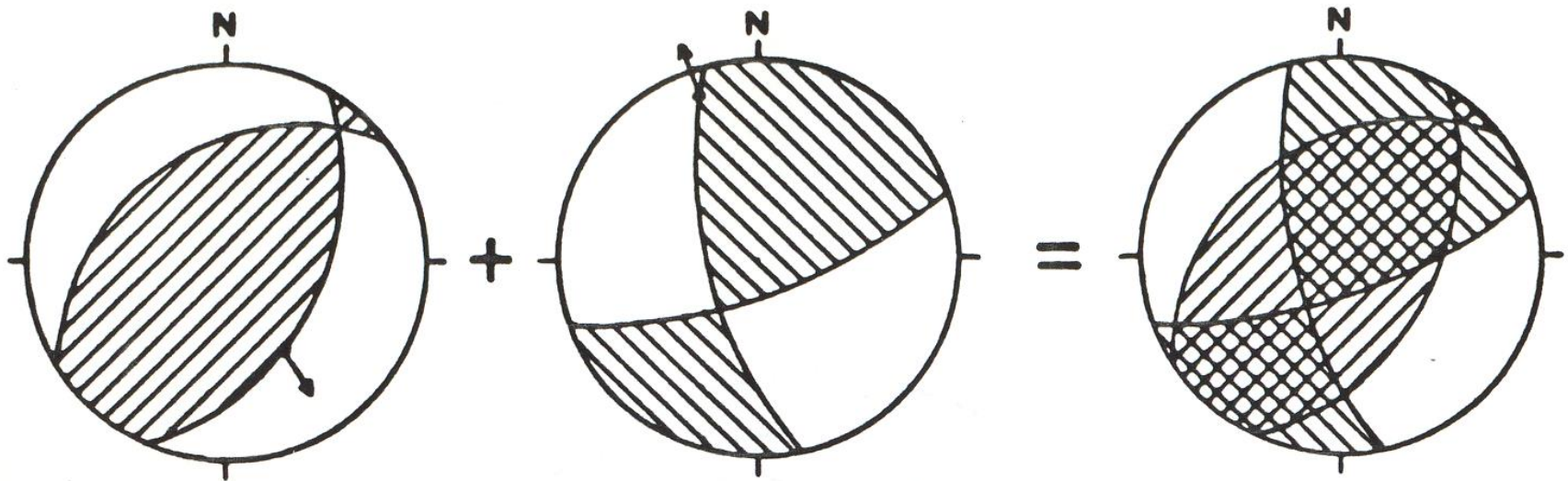






Separação de estruturas de diferentes gerações





Método gráfico de Angelier & Mechler (1977)  
ou método de Angelier

