INSTITUTO GEOFISICO DO INFANTE DOM LUIZ
CENTRO DE GEOFISICA DA UNIVERSIDADE DE LISBOA

Cap 4.
Paleomagnetismo e Cinemática de Placas

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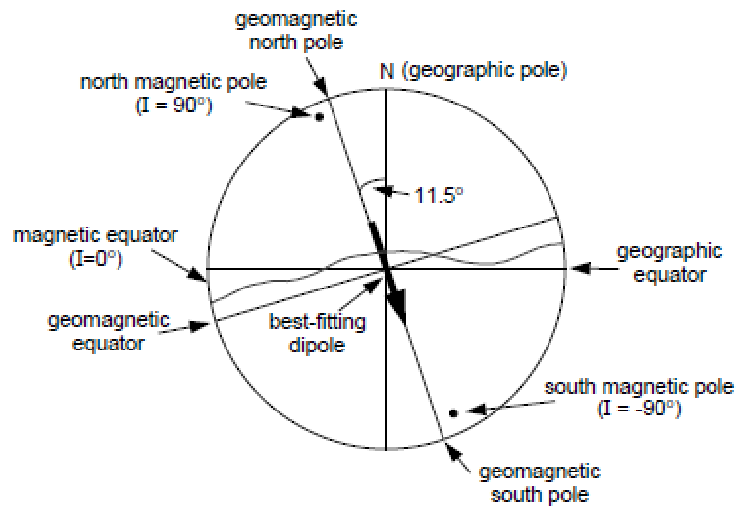
IDL-FCUL

Pólos paleomagnéticos

Pólo Magnético — Região da Superfície da Terra onde a inclinação do CMT é de 90º (PM Norte) ou –90º (PM Sul).

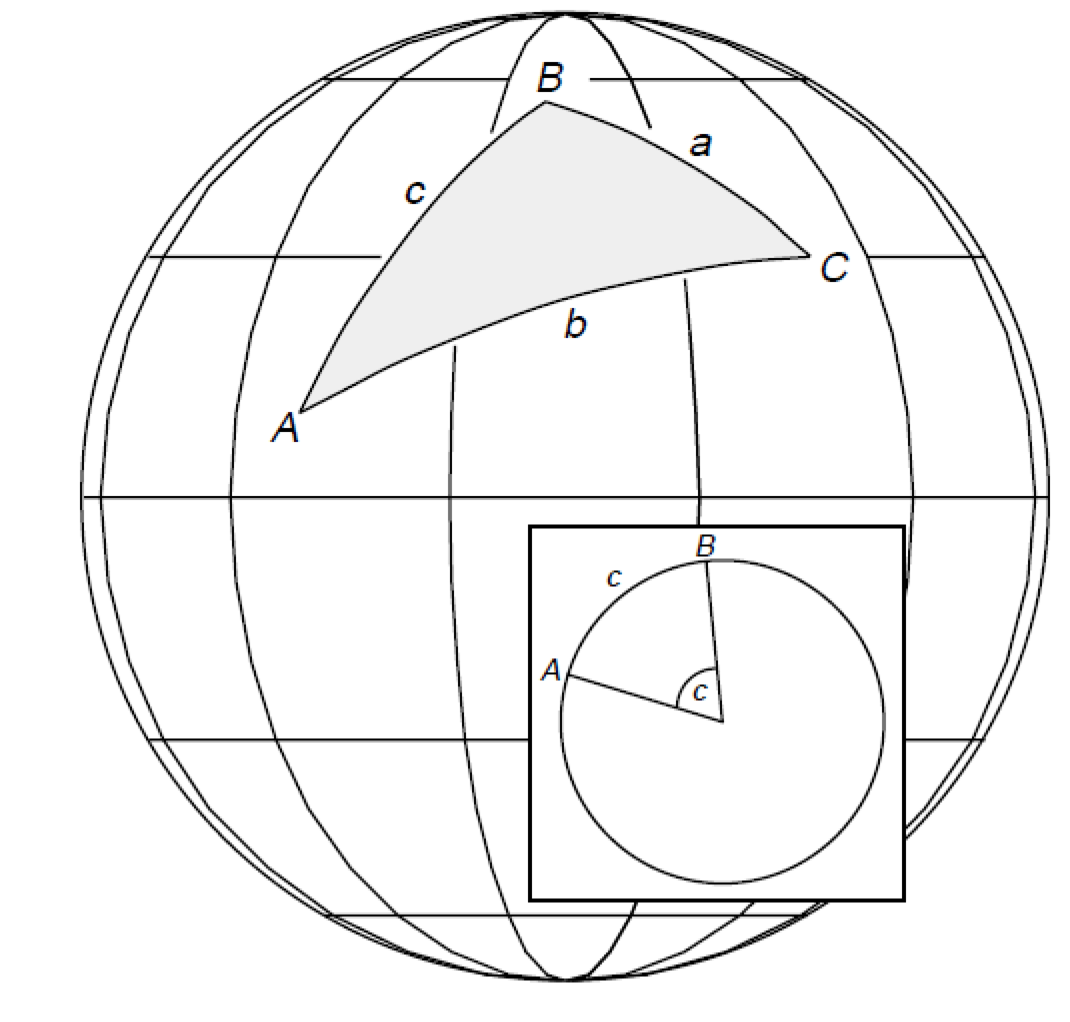
Pólo Geomagnético — Pontos onde o Eixo do Dipólo que melhor aproxima o CMT intersecta a Superfície da Terra.

Pólo Virtual Geomagnético — Ponto sobre a superfície da Terra que melhor aproxima a localização do Pólo Geomagnético da altura da aquisição da magnetização remanescente por uma dada formação.



Pólo Paleomagnético — Ponto sobre a Superfície da Terra correspondente a uma média de VGP para um período de 10^4 a 10^5 anos, que supomos representar a **posição relativa** do Pólo Geográfico.

Determinação do Pólo Magnético a partir de I, D e coordenadas do sitio



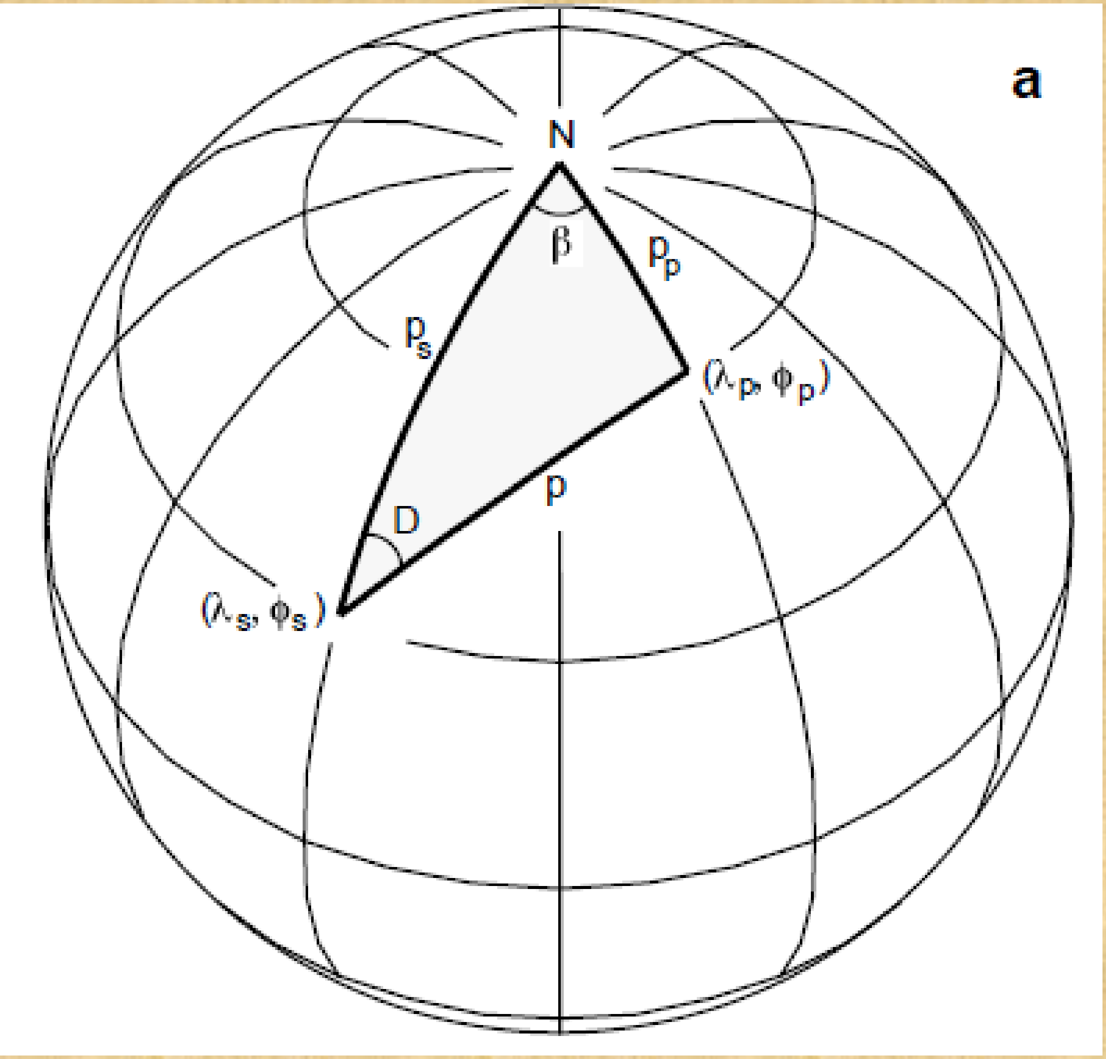
Lei dos cosenus:

$$\cos a = \cos b \cos c + \sin b \sin c \cos A$$

Lei dos senus:

$$\frac{\sin a}{\sin A} = \frac{\sin b}{\sin B} = \frac{\sin c}{\sin C}$$

Determinação do Pólo Magnético a partir de I, D e coordenadas do sitio



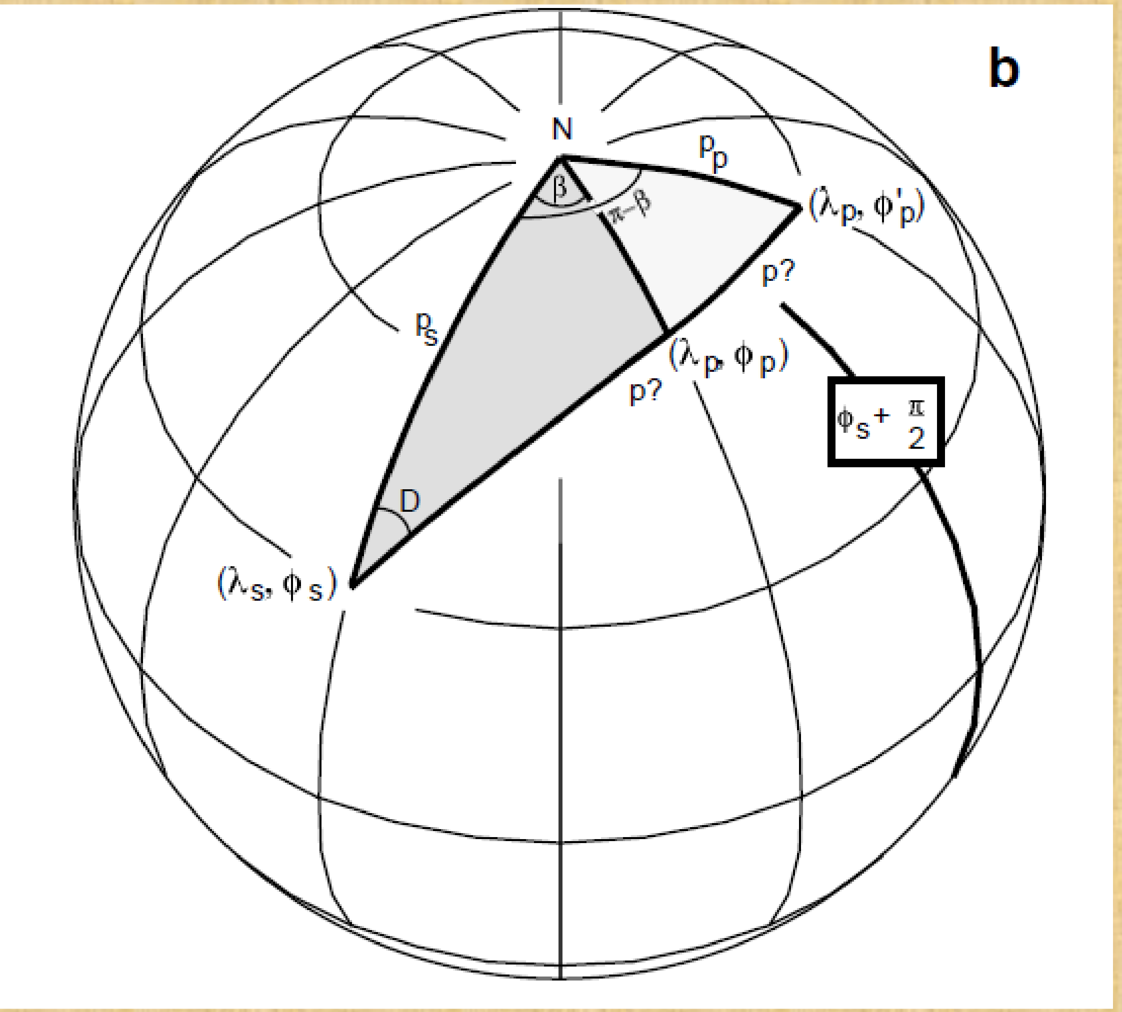
Lei do dipólo:

$$p = \cot^{-1}\left(\frac{\tan I}{2}\right) = \tan^{-1}\left(\frac{2}{\tan I}\right)$$

$$\lambda_p = \sin^{-1}(\sin\lambda_s \cos p + \cos\lambda_s \sin p \cos D)$$

$$\beta = \sin^{-1}\left(\frac{\sin p \sin D}{\cos\lambda_p}\right)$$

Determinação do Pólo Magnético a partir de I, D e coordenadas do sitio



$$\beta = \sin^{-1}\left(\frac{\sin p \sin D}{\cos \lambda_p}\right)$$

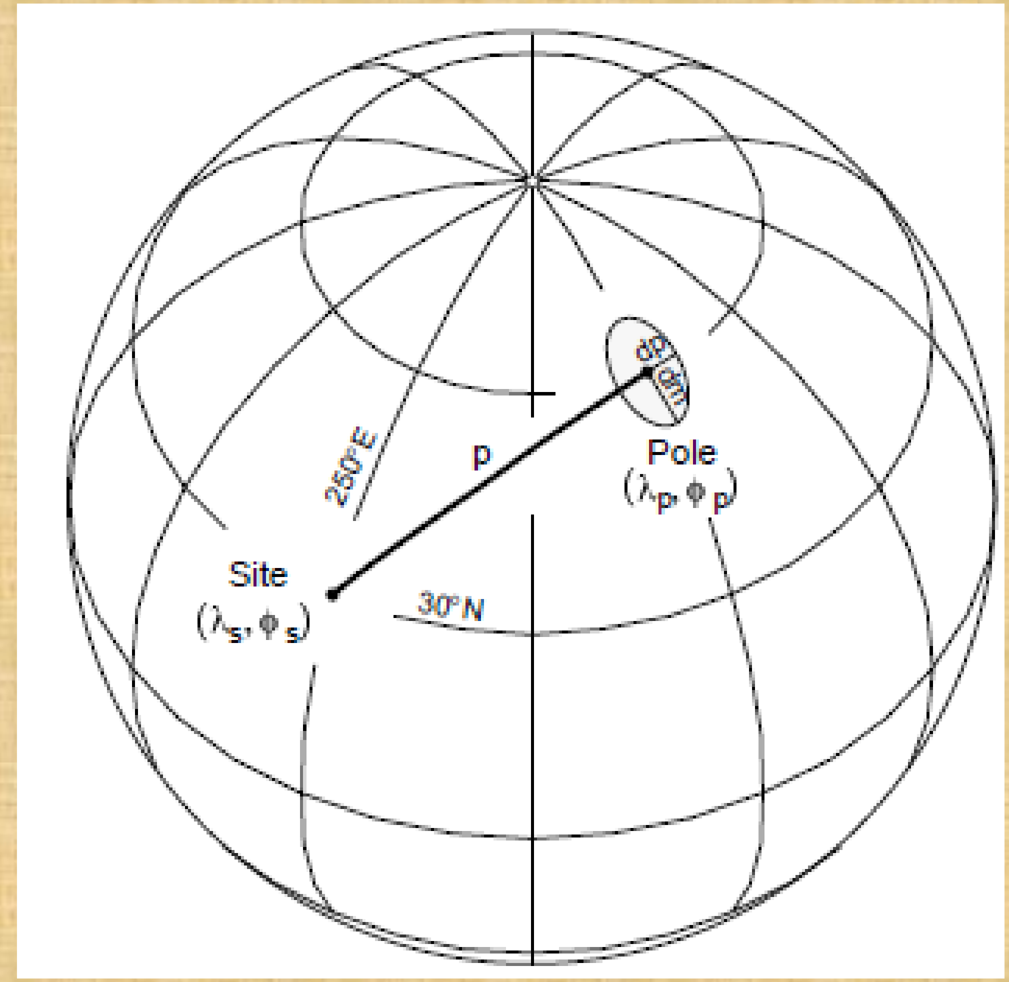
$\cos p \geq \sin \lambda_p \sin \lambda_s$

$$\phi_p = \phi_s + \beta$$

$\cos p < \sin \lambda_p \sin \lambda_s$

$$\phi_p = \phi_s + \pi - \beta$$

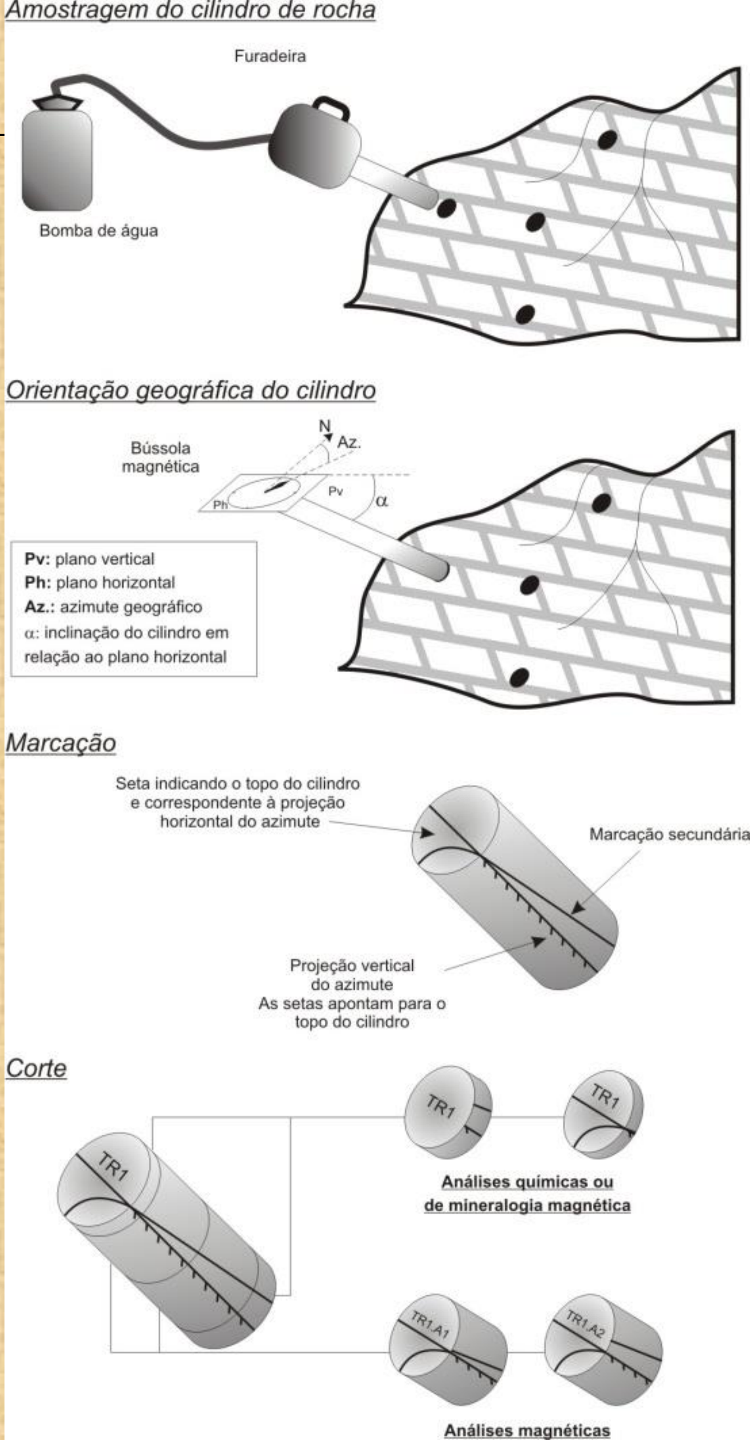
Determinação do Dp, Dm



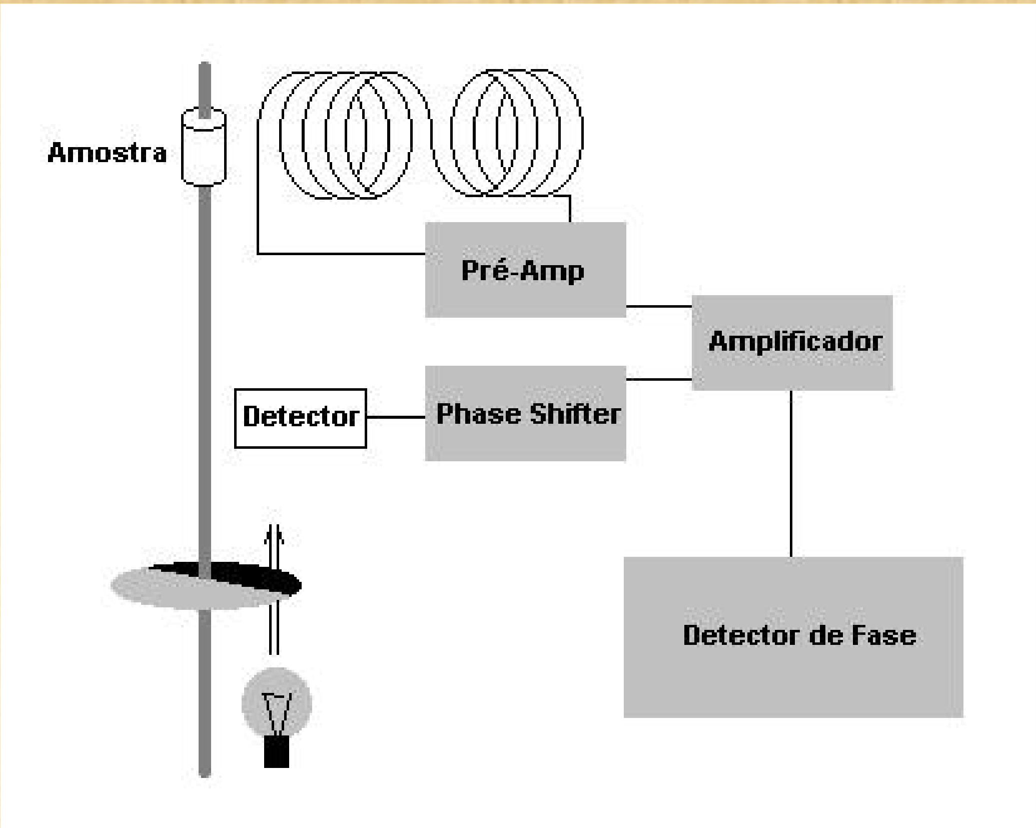
$$dp = 2\alpha_{95}\left(\frac{1}{1+3\cos^2 I}\right)$$

$$dm = \alpha_{95}\frac{\sin p}{\cos I}$$

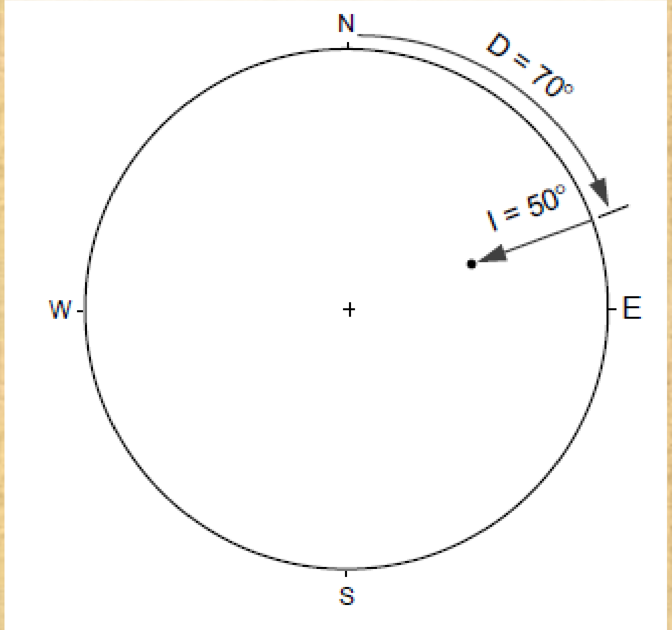
Paleomagnetismo experimental: amostragem



Paleomagnetismo experimental: medidas

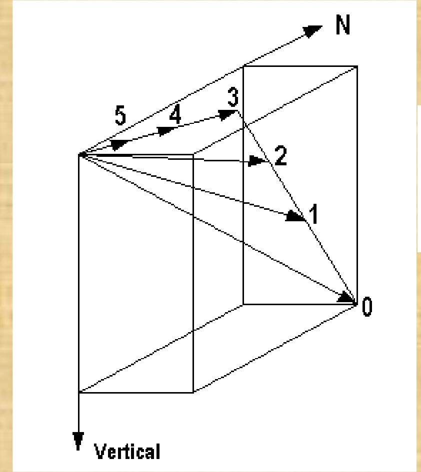


Magnetômetro rotativo (spinner):



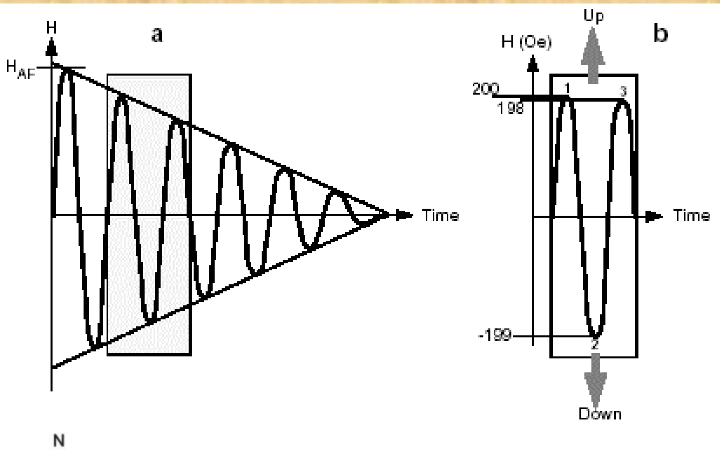
Projecção estereográfica

Paleomagnetismo experimental: procedimentos de desmagnetização

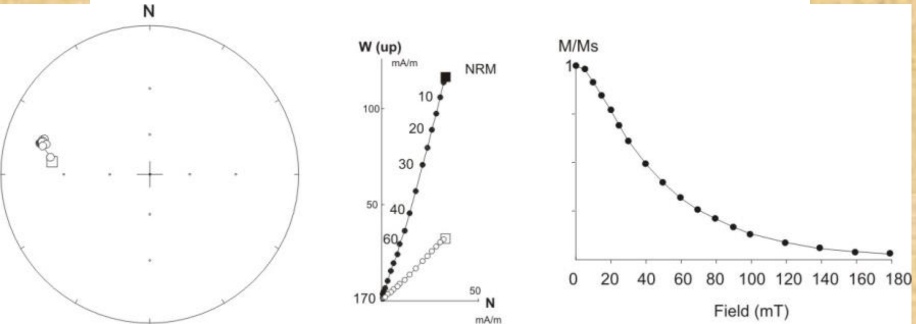


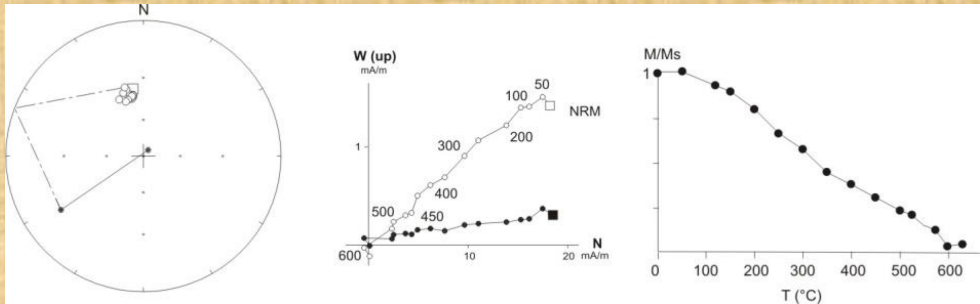
$$\tau = \frac{1}{C}\exp\left(\frac{vH_C J_S}{2kT}\right)$$

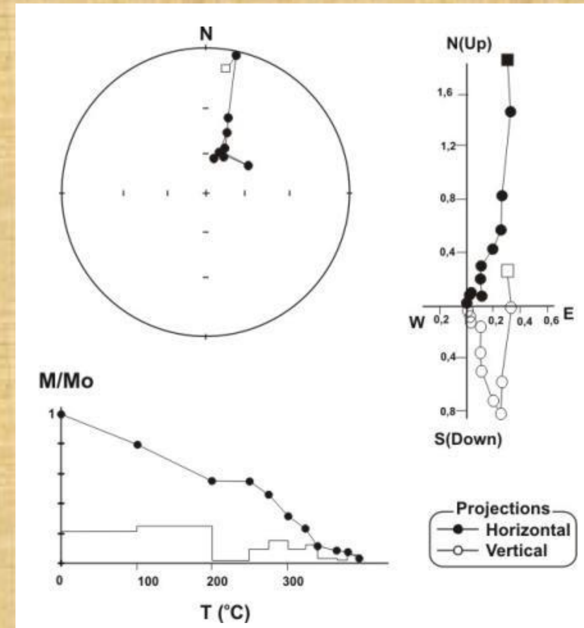
Desmagnetização AF



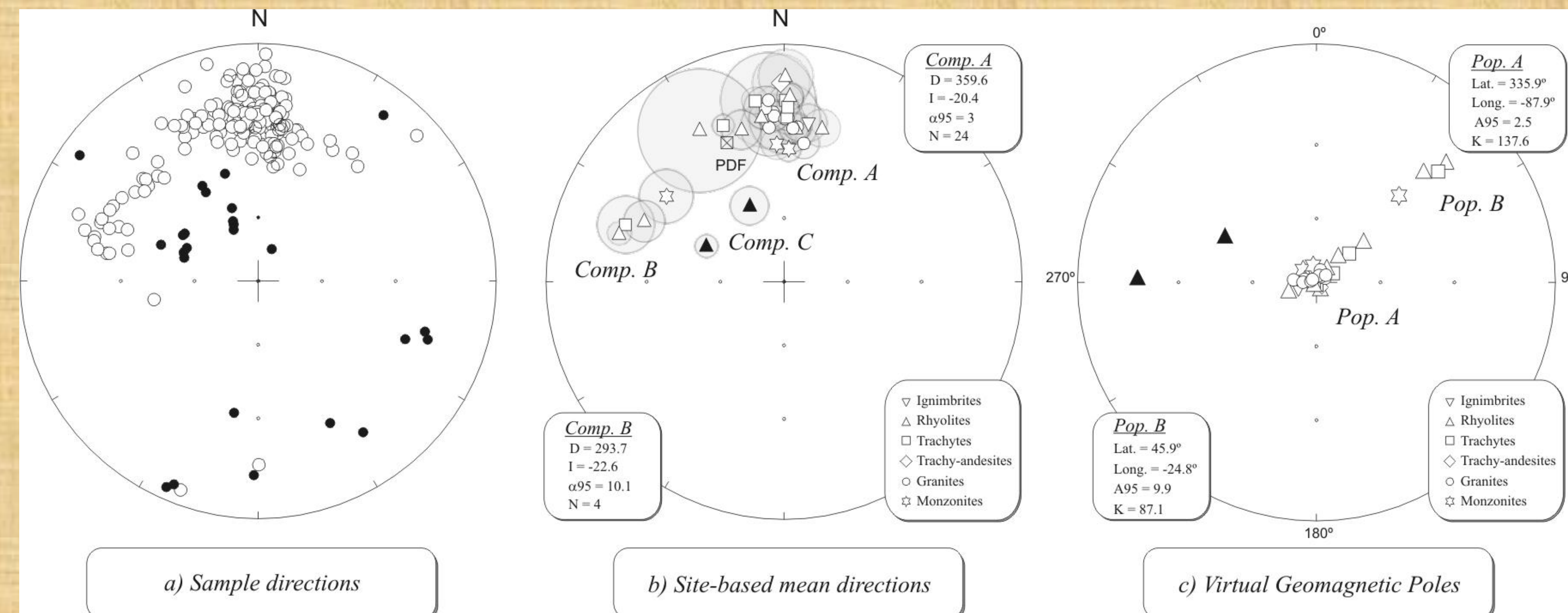
Desmagnetização térmica







N
N(Up)
1,6
1,2
0,8
0,4
W
0,2
0,2
0,4
0,6
E
0,4
0,8
S(Down)
M/Mo
1
0
100
200
300
T (°C)
Projections
Horizontal
Vertical



N
N
Comp. A
D = 359.6
I = -20.4
α95 = 3
N = 24
PDF
Comp. A
Comp. C
Comp. B
Comp. B
D = 293.7
I = -22.6
α95 = 10.1
N = 4
Ignimbrites
Rhyolites
Trachytes
Trachy-andesites
Granites
Monzonites
0º
270º
90º
180º
Pop. A
Lat. = 335.9º
Long. = -87.9º
A95 = 2.5
K = 137.6
Pop. B
Pop. A
Pop. B
Lat. = 45.9º
Long. = -24.8º
A95 = 9.9
K = 87.1
Ignimbrites
Rhyolites
Trachytes
Trachy-andesites
Granites
Monzonites
a) Sample directions
b) Site-based mean directions
c) Virtual Geomagnetic Poles

Paleomagnetismo experimental: a factor Q

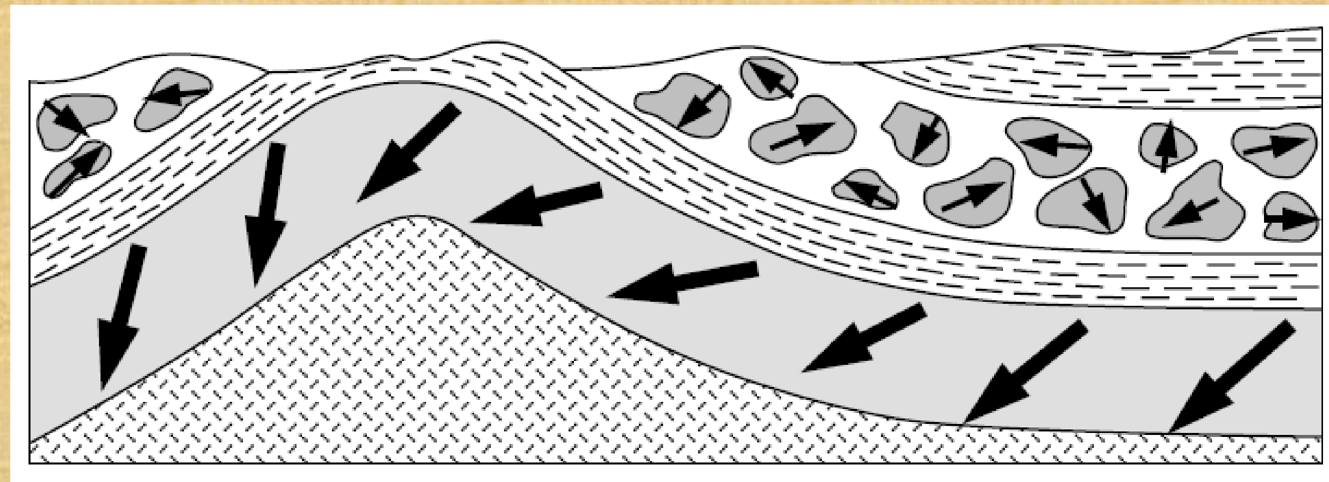
Van der Voo (1990):

- Idade bem definida da rocha e presunção de que a magnetização é da mesma idade
- Quantidade suficiente de amostras: N>24, k≥10 e a95≤16
- Desmagnetização adequada incluindo a análise em componentes principais (ACP)
- Testes de consistência que constringem a idade da magnetização
- Controlo estructural e coerência tectónica com o craton ou os blocos envolvidos
- Presencia de inversões
- Não ter similaridades com pólos de idade mais recentes

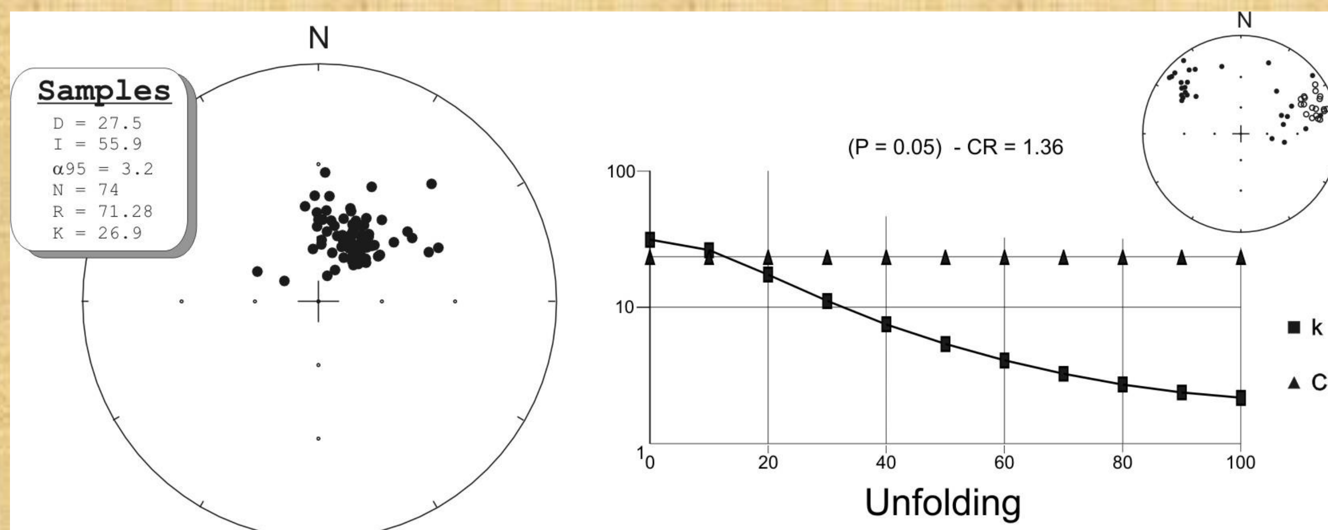
Paleomagnetismo experimental: testes de consistência

Teste do conglomerado

Teste da dobra



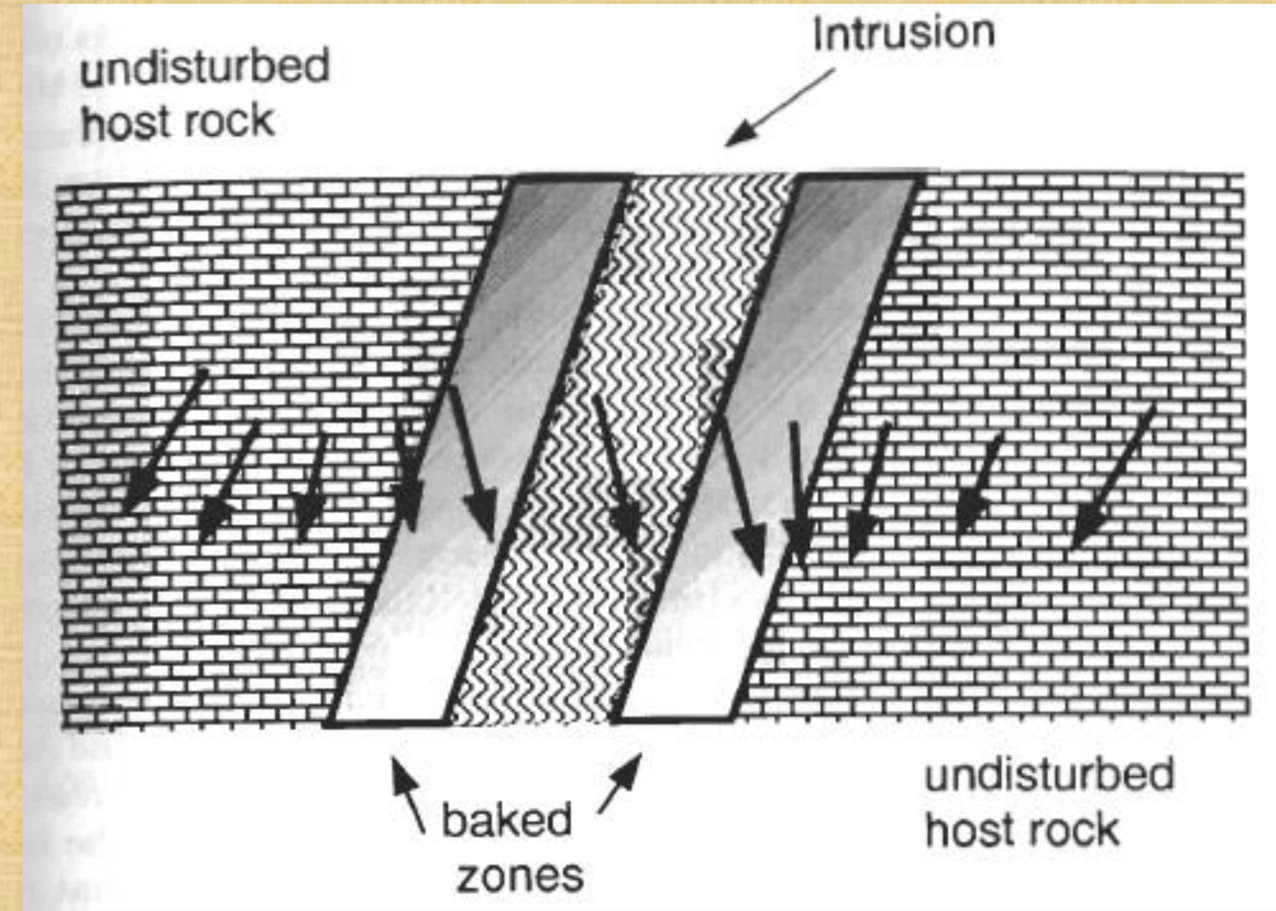
Butler, 1992



Trindade et al., 2003.

Paleomagnetismo experimental: testes de consistência

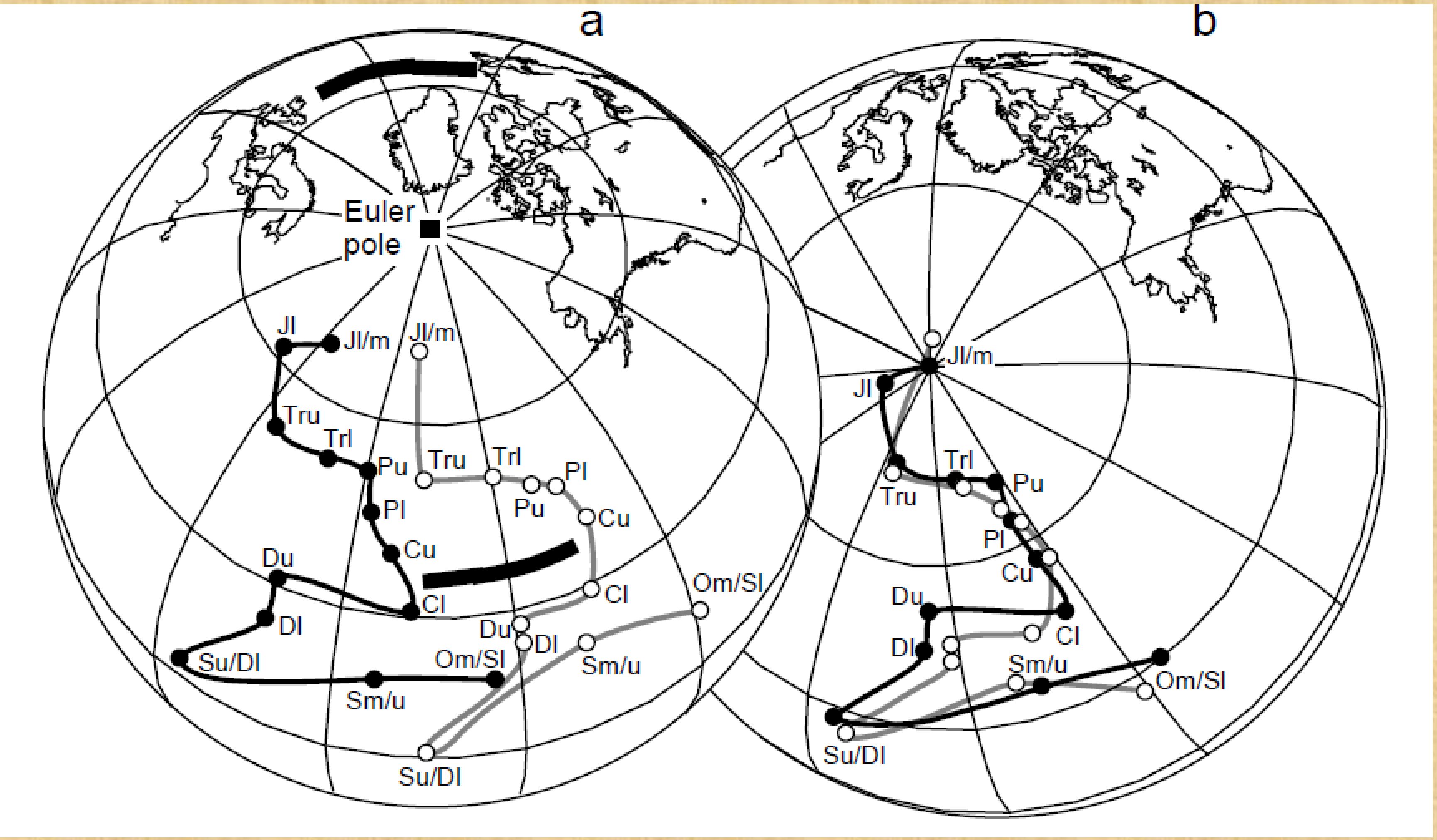
Teste do contacto



Tauxe, 2002.

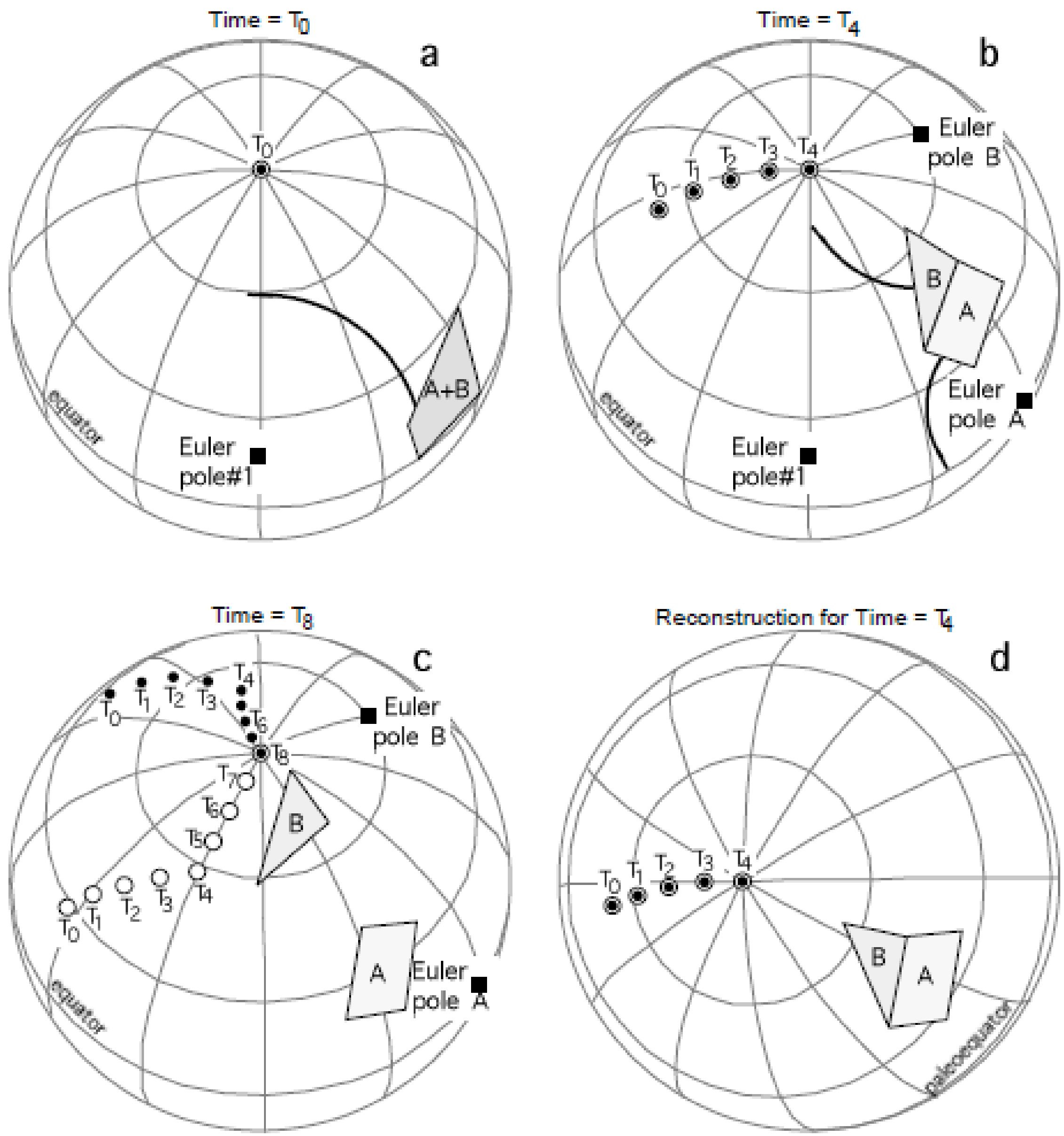
Curva de Deriva Aparente Polar

Pólo de Euler: 88.5 ºN, 27.7 ºE, 38º sentido horário



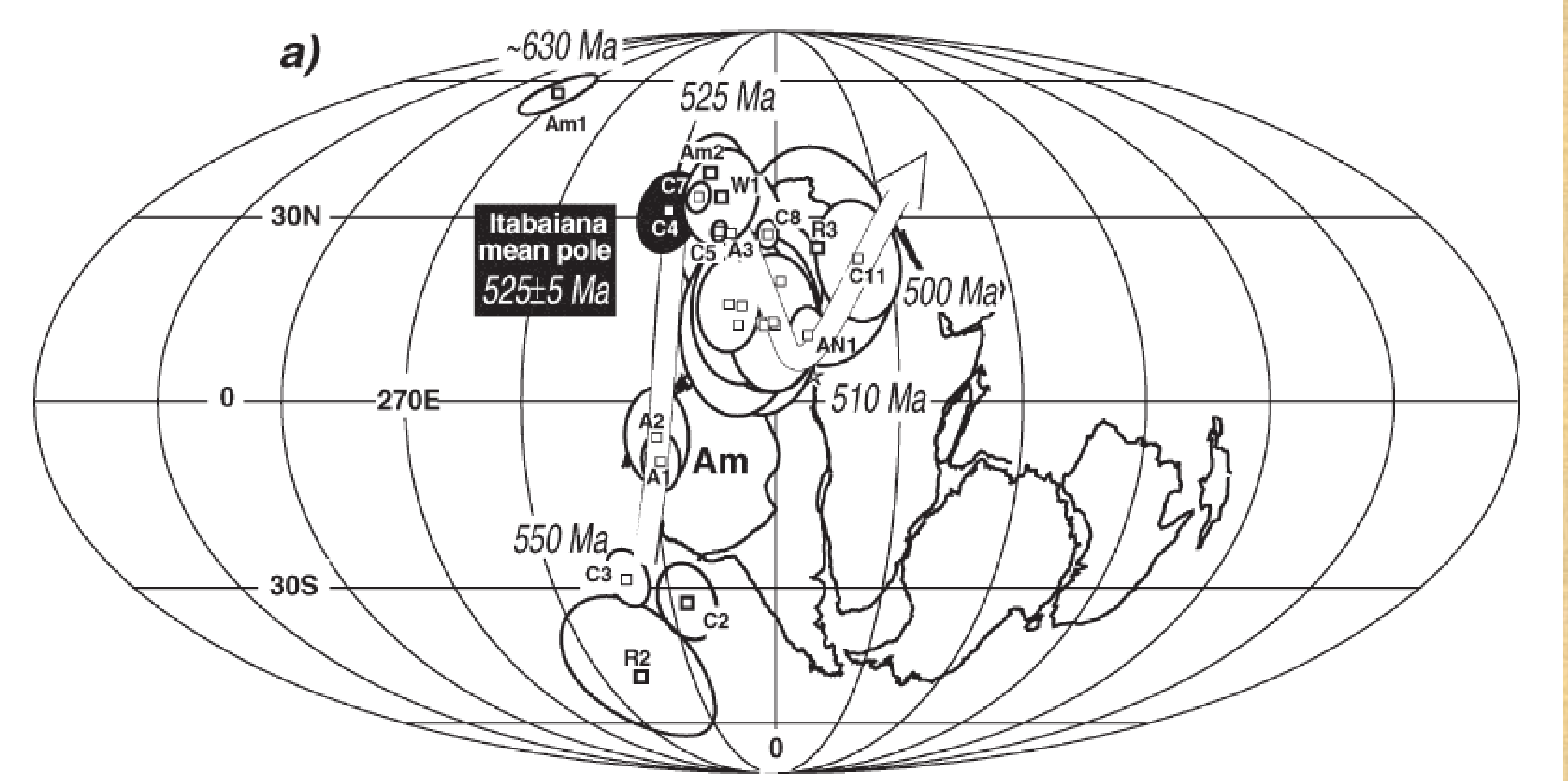
Butler, 2002.

Curva de Deriva Aparente Polar e pólo de Euler



Butler, 2002.

Curva de Deriva Aparente Polar



Trindade et al., 2006. EPSL 244, 361-377.

CALCULATION OF A MAGNETIC POLE FROM THE DIRECTION OF THE MAGNETIC FIELD

The trigonometry involved in deriving the expressions for calculating a magnetic pole from a magnetic field direction is shown in Figure A.3a. The site is at geographic latitude λ_s and longitude ϕ_s and the pole is at geographic latitude λ_p and longitude ϕ_p. We form a spherical triangle with apices at (λ_s, ϕ_s), (λ_p, ϕ_p), and the north geographic pole, *N*. The colatitude (angular distance from the north geographic pole) of the site is p_s, while the colatitude of the magnetic pole is p_p.

The magnetic colatitude, *p*, is the great-circle angular distance of the site from the magnetic pole. This angular distance is determined from the dipole formula (Equation (A.10)):

$$p = \cot^{-1}\left(\frac{\tan I}{2}\right) = \tan^{-1}\left(\frac{2}{\tan I}\right) \tag{A.24}$$

Now we need to find p_p by using the Law of Cosines:

$$\cos p_p = \cos p_s \cos p + \sin p_s \sin p \cos D \tag{A.25}$$

Using the definition of the colatitude,

$$p_p = \frac{\pi}{2} - \lambda_p \quad \text{and} \quad p_s = \frac{\pi}{2} - \lambda_s \tag{A.26}$$

Substituting these expressions for p_p and p_s in Equation (A.25) leads to

$$\cos\left(\frac{\pi}{2} - \lambda_p\right) = \cos\left(\frac{\pi}{2} - \lambda_s\right)\cos p + \sin\left(\frac{\pi}{2} - \lambda_s\right)\sin p \cos D \tag{A.27}$$

Using

$$\cos\left(\frac{\pi}{2} - x\right) = \sin x \quad \text{and} \quad \sin\left(\frac{\pi}{2} - x\right) = \cos x$$

in Equation (A.27) yields

$$\sin\lambda_p = \sin\lambda_s \cos p + \cos\lambda_s \sin p \cos D \tag{A.28}$$

and

$$\lambda_p = \sin^{-1}(\sin\lambda_s \cos p + \cos\lambda_s \sin p \cos D) \tag{A.29}$$

which is Equation (7.2).

The next step is to determine the angle β, which is the difference in longitude between the pole and the site (Figure A.3a). Applying the Law of Sines to the spherical triangle in Figure A.3 yields

$$\frac{\sin p}{\sin\beta} = \frac{\sin p_p}{\sin D} \tag{A.30}$$

Rearrange Equation (A.30) to give

$$\sin\beta = \frac{\sin D}{\sin p_p} \sin p \tag{A.31}$$

Now substitute $p_p = (\pi / 2) - \lambda_p$ to yield

$$\sin\beta = \frac{\sin D}{\sin\left(\frac{\pi}{2} - \lambda_p\right)} \sin p \tag{A.32}$$

and

$$\sin\beta = \frac{\sin D}{\cos\lambda_p} \sin p \tag{A.33}$$

Now solve for β to give

$$\beta = \sin^{-1}\left(\frac{\sin p \sin D}{\cos\lambda_p}\right) \tag{A.34}$$

which is Equation (7.3).

As given by Equation (A.34), β is limited to the range $-\pi / 2$ to $+\pi / 2$. But this raises an important ambiguity in the derivation. Simply adding b to the site longitude would not allow the pole longitude to differ from the site longitude by more than $\pi / 2$. This ambiguity is shown schematically in Figure A.3b. As viewed from the site at λ_s, ϕ_s, the above expression for β would not allow the pole to be in the longitudinal hemisphere opposite from the site (beyond the longitude shown by the heavy line in Figure A.3b).

The ambiguity is whether the pole longitude is given by (1) $\phi_p = \phi_s + \beta$ (as shown in Figure A.3a) <u>or</u> (2) $\phi_p = \phi_s + (\pi - \beta)$. These two possibilities are shown by the two spherical triangles in Figure A.3b. The smaller triangle has apices at (λ_s, ϕ_s), (λ_p, ϕ_p), and *N*; the larger triangle has apices at (λ_s, ϕ_s), (λ_p, ϕ'_p), and *N*. Because λ_p is the same for either of the two possible poles, p_p is the same angular distance for either triangle. So we must devise a test to determine which of the two possible spherical triangles applies to a particular calculation of a magnetic pole position.

Apply the Law of Cosines to the two triangles in Figure A.3b. For the smaller triangle,

$$\cos p = \cos p_p \cos p_s + \sin p_p \sin p_s \cos\beta \tag{A.35}$$

while for the larger triangle,

$$\cos p = \cos p_p \cos p_s + \sin p_p \sin p_s \cos(\pi - \beta) \tag{A.36}$$

Now substitute

$$p_p = \left(\frac{\pi}{2} - \lambda_p\right),\ p_s = \left(\frac{\pi}{2} - \lambda_s\right), \cos(\pi - \beta) = -\cos\beta,\ \cos\left(\frac{\pi}{2} - \lambda_p\right) = \sin\lambda_p,$$

$$\text{and } \sin\left(\frac{\pi}{2} - \lambda_p\right) = \cos\lambda_p \tag{A.37}$$

into Equations (A.35) and (A.36) to yield

$$\cos p = \sin\lambda_p \sin\lambda_p + \cos\lambda_p \cos\lambda_p \cos\beta \tag{A.38}$$

for the smaller triangle and

$$\cos p = \sin\lambda_p \sin\lambda_s - \cos\lambda_p \cos\lambda_s \cos\beta \tag{A.39}$$

for the larger triangle.

At this point we realize that λ_p, λ_s, and β are all limited to the range $-\pi/2$ to $+\pi/2$. Within this range, the product $\cos\lambda_p \cos\lambda_s \cos\beta$ will always be positive. So if we find $\cos p \geq \sin\lambda_p \sin\lambda_s$, this indicates that we must be dealing with the smaller spherical triangle in Figure A.3b, and pole longitude is given by

$$\phi_p = \phi_s + \beta \tag{A.40}$$

But if we find $\cos p < \sin\lambda_p \sin\lambda_s$, we must be dealing with the larger triangle in Figure A.3b, for which

$$\phi_p = \phi_s + \pi - \beta \tag{A.41}$$

This development explains the conditional tests and alternative methods of calculating ϕ_p given by Equations (7.4) through (7.7).