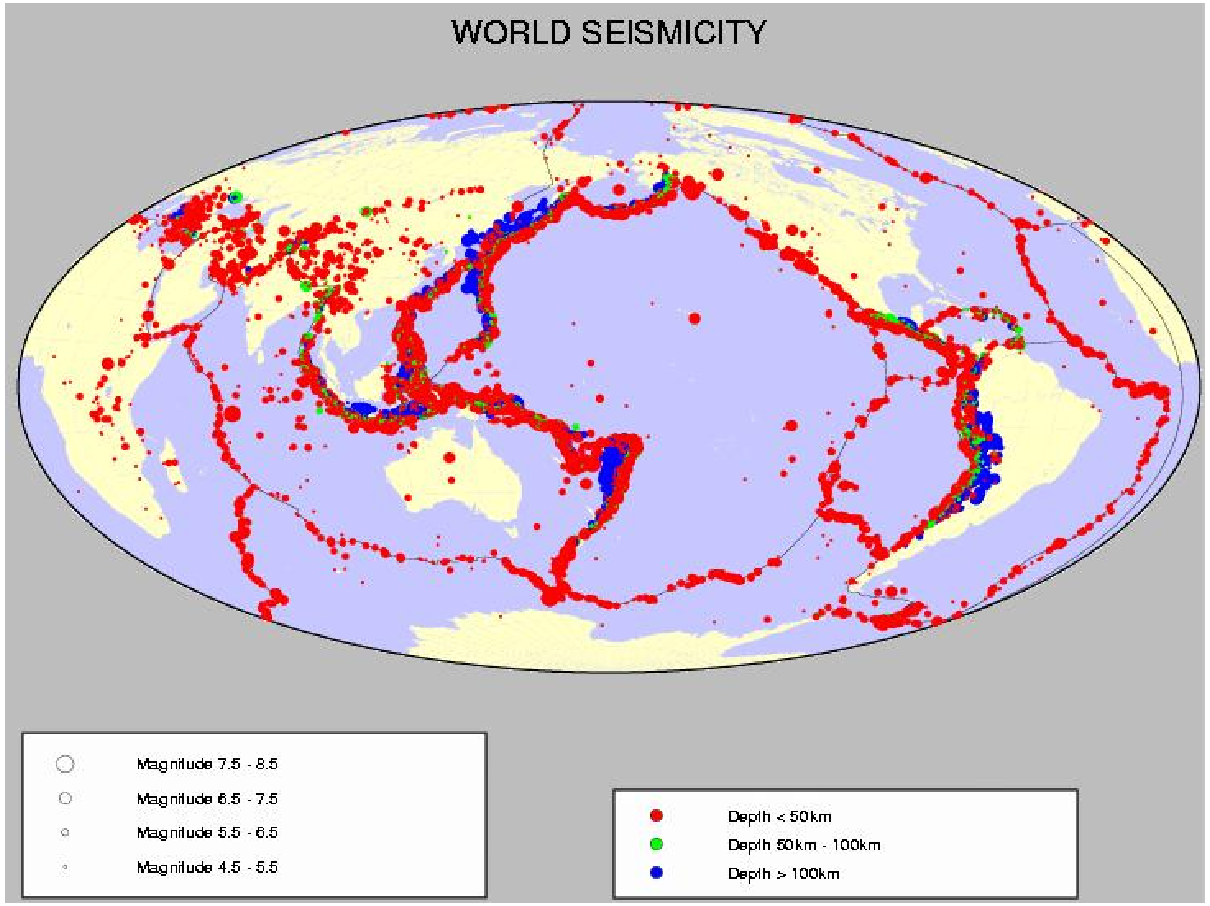
RIGID PLATE TECTONICS

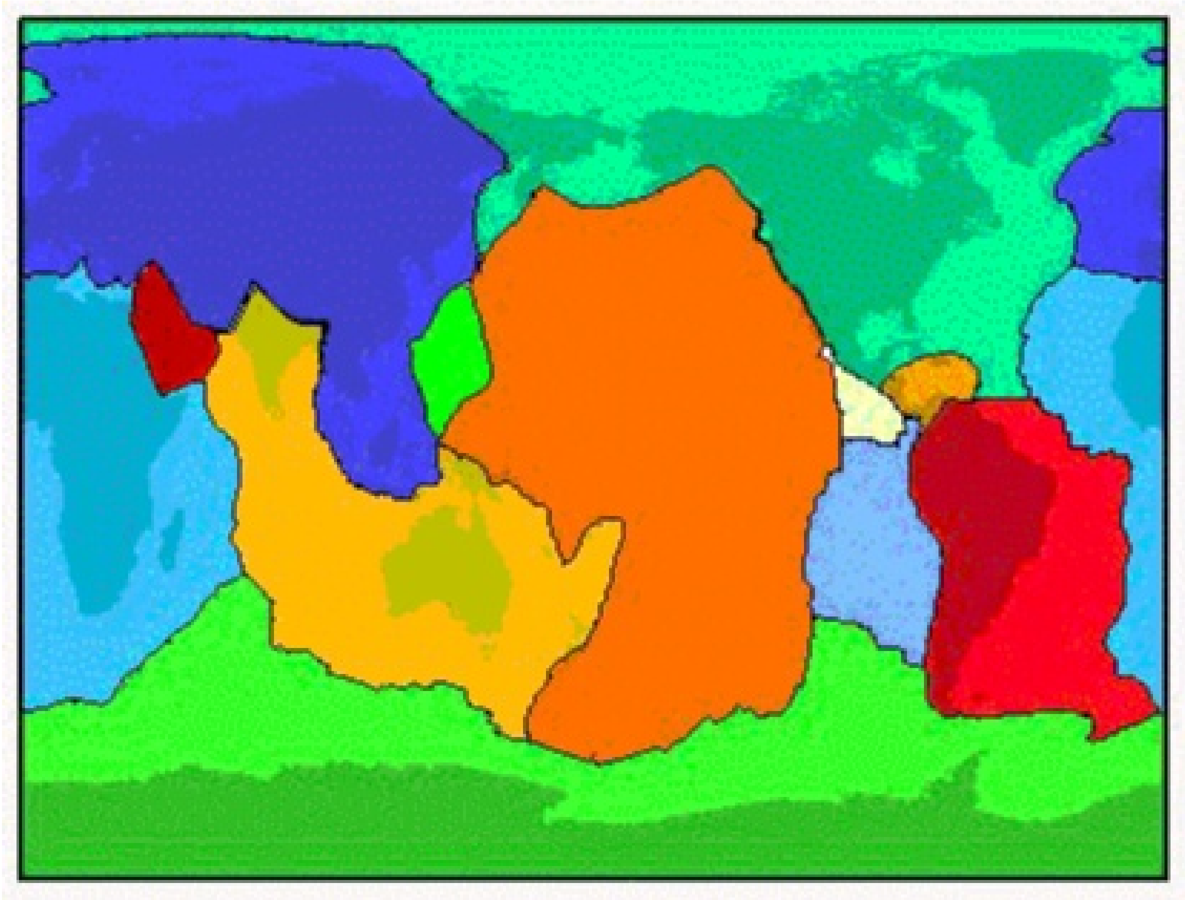
- Plate definition
- Plate motion : Euler pole
- Geological model : Nuvel-1A
- Geodetic model : ITRF
- Rigid plate rotations
- Plate deformation : strain and rotation tensors

World seismicity



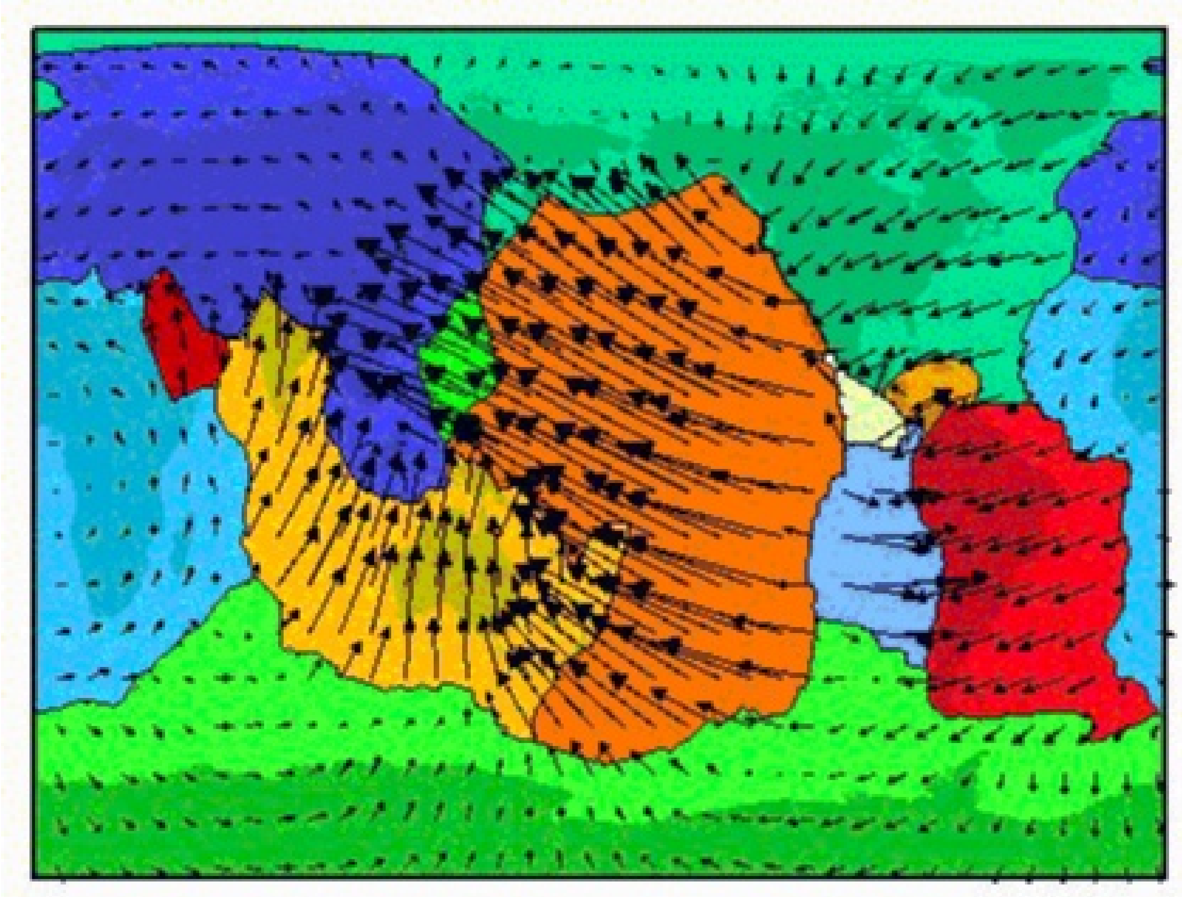
The Earth surface is cut by seismic « lines », separting quite areas, i.e. plates.

Plate geometry



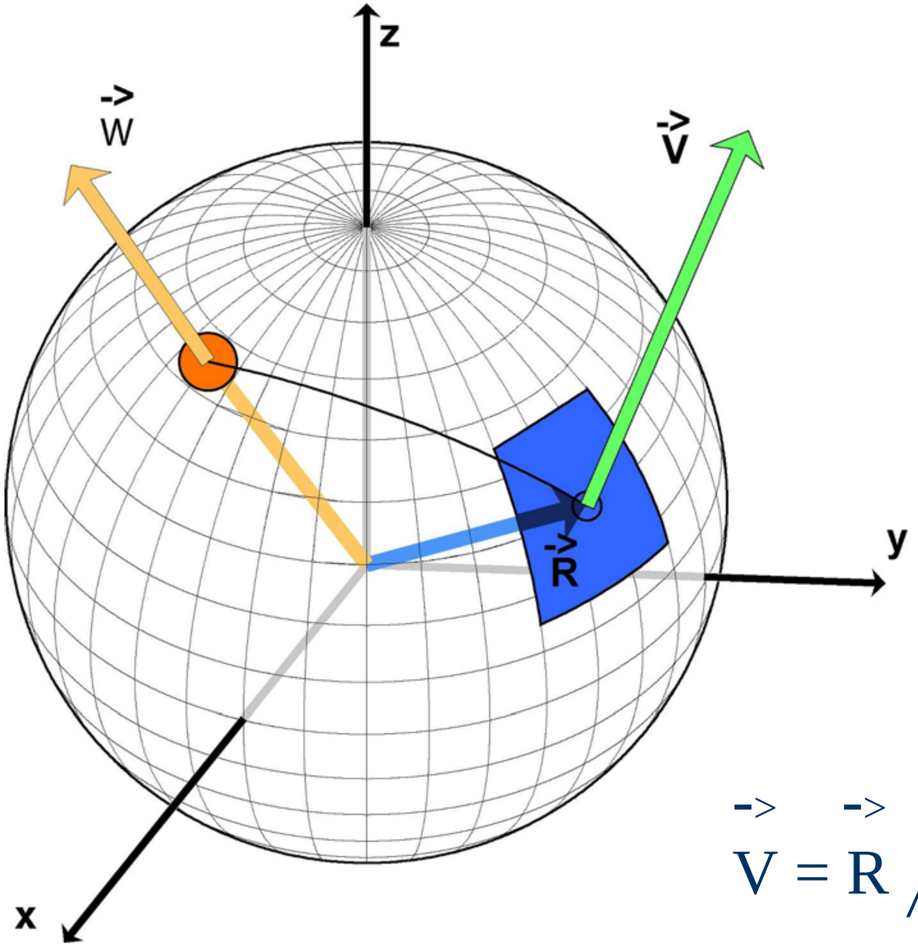
There are 12 main plates

Plate motion



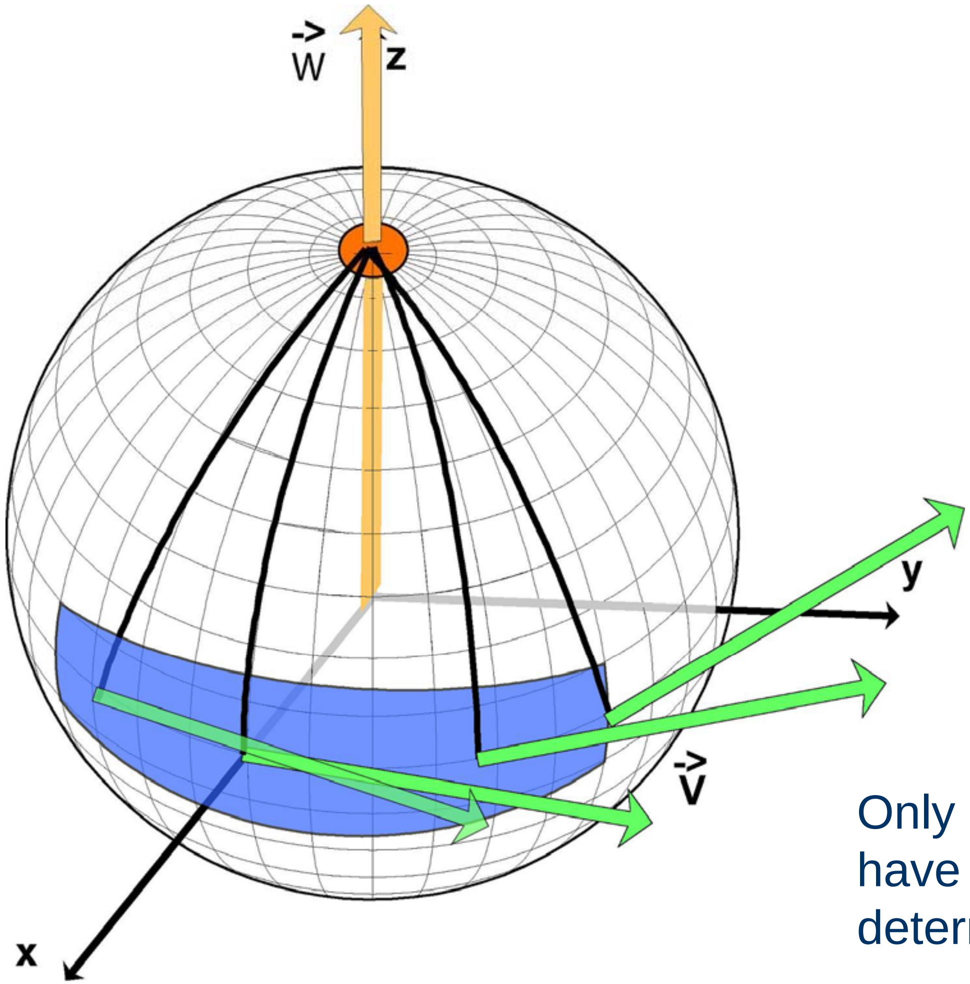
Plates move : it is plate tectonics

Rotation on a sphere



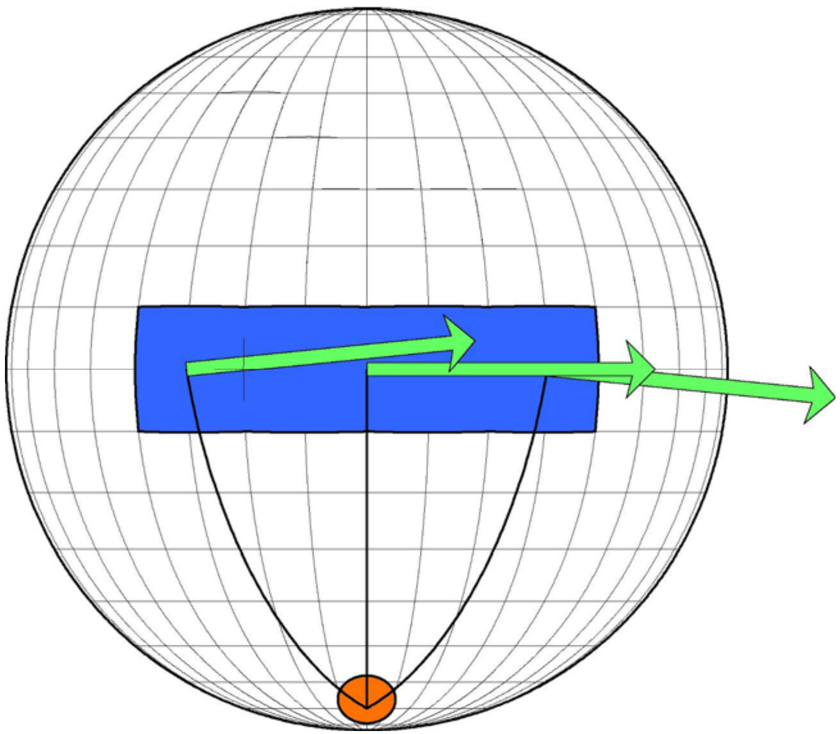
$$\vec{V} = \vec{R} \wedge \vec{W}$$

Finding a pole



Only large plates have well determined poles

Effect of velocity uncertainty



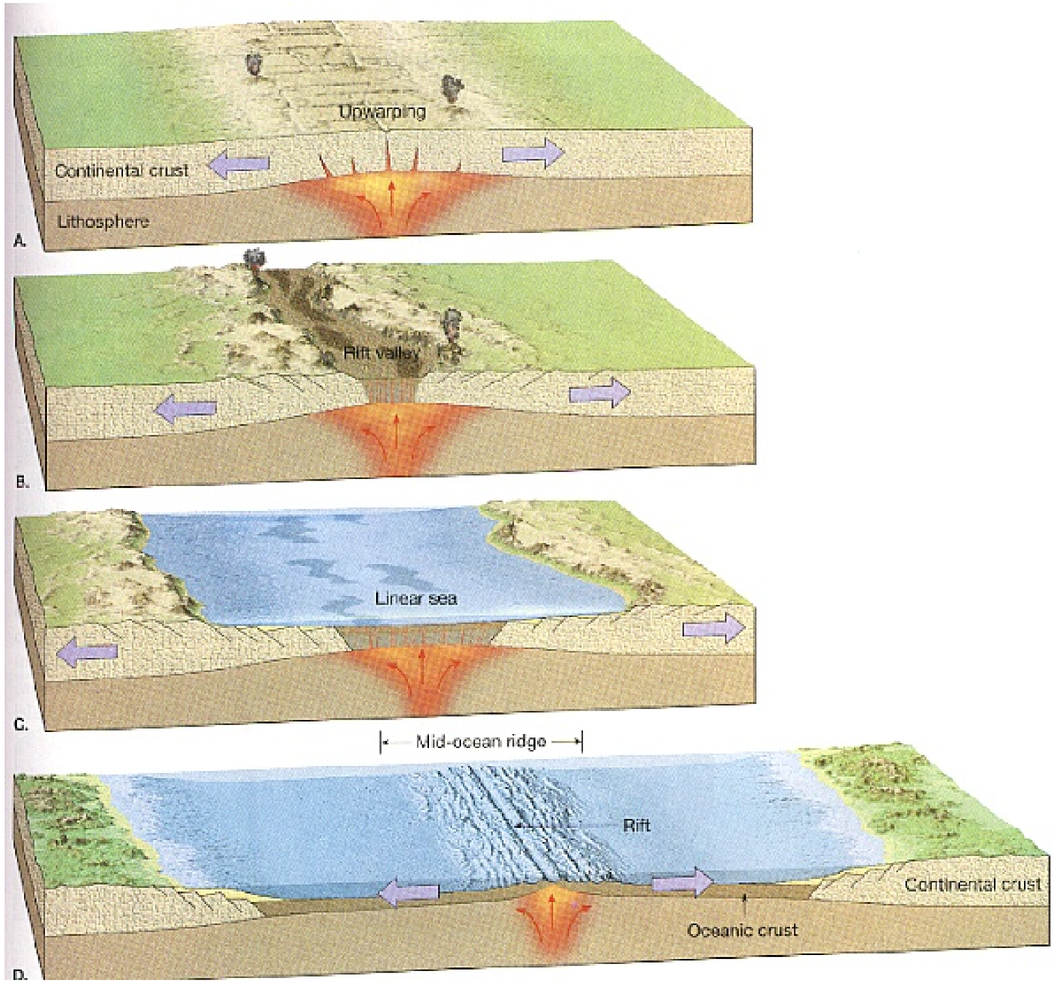
Slightely different velocities can give very different poles

Or reverse :

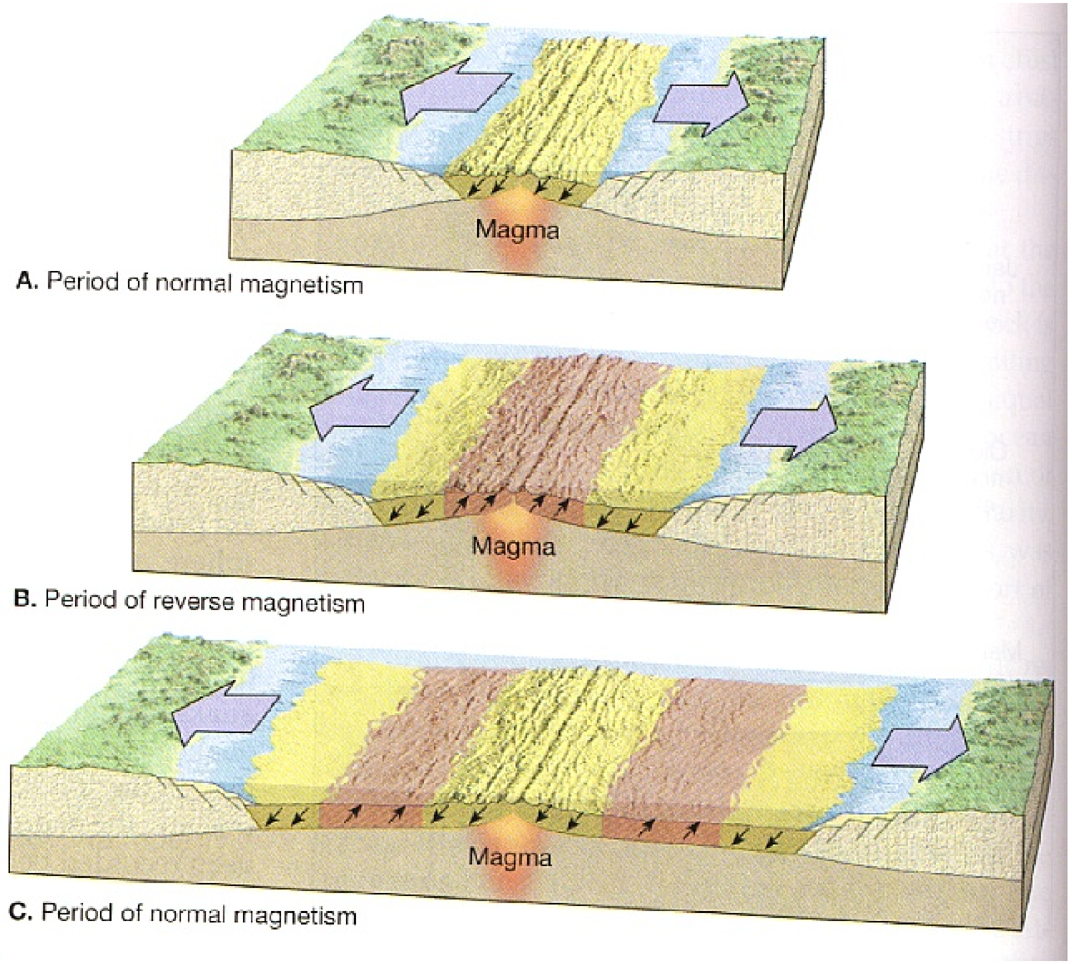
Very different poles can give quite similar velocities

Pole positions don't matter.
only velocities do !!!!

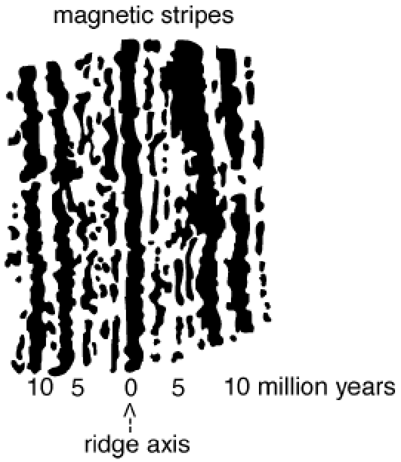
Geological model : how it works
Rates : continental drifting



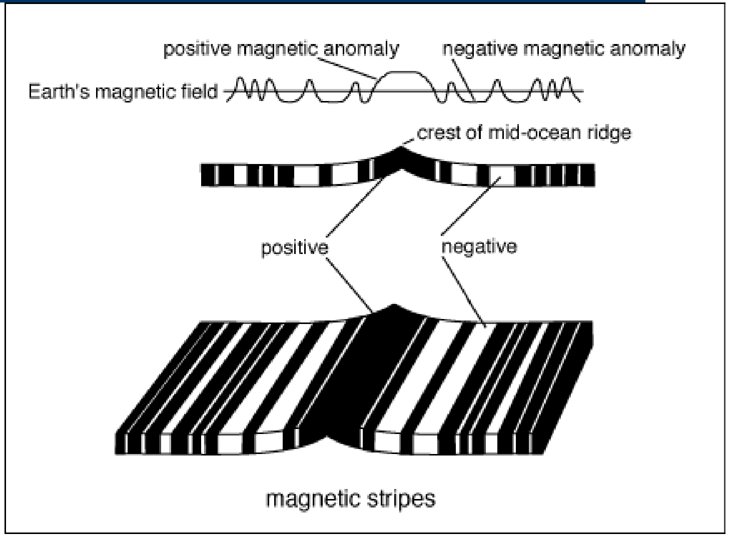
Geological model : how it works
Rates : generation of oceanic crust and sea floor magnetic anomalies

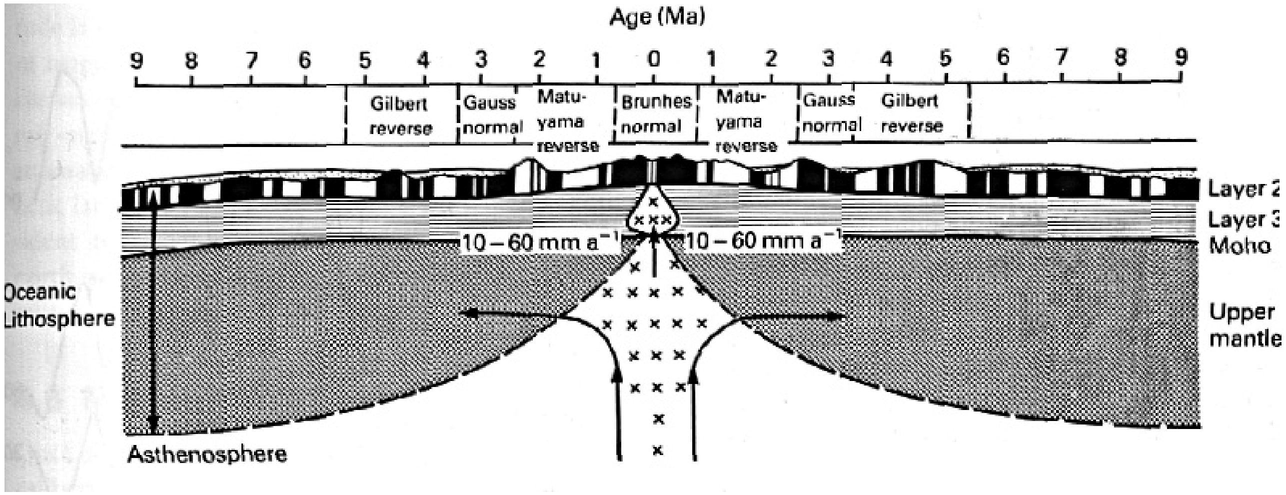


Geological model : how it works
Rates : Vine and Matthews hypothesis



Pattern created by magnetic stripes along the Mid-Atlantic Ridge south of Iceland.





Geological model : how it works
Rates : unecrtainties from magnetic time scale

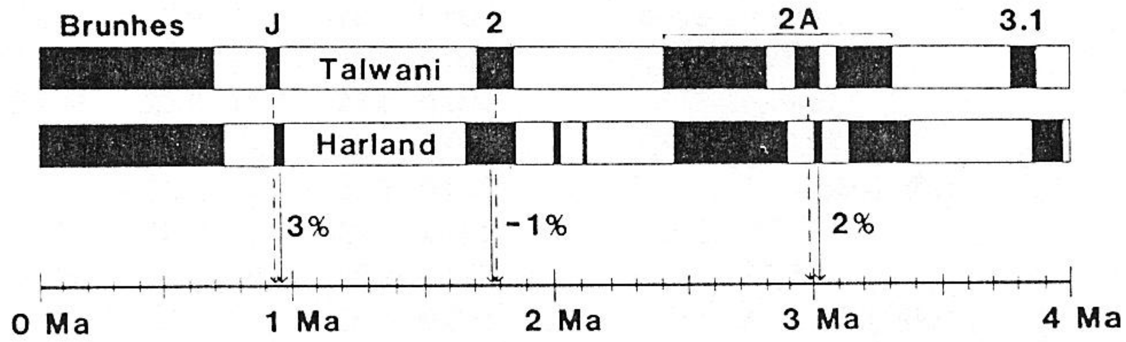


Figure 1. Comparison since 4.0 Ma of the geomagnetic reversal time-scale used here (Harland *et al.* 1982) with the time-scale used by Chase (1978) and Minster & Jordan (1978) (Talwani *et al.* 1971). We determined rates by seeking the best fit to the centre of anomaly 2A, which is 2 per cent older in the Harland *et al.* time-scale than in the Talwani *et al.* time-scale.

Geological model : how it works

directions

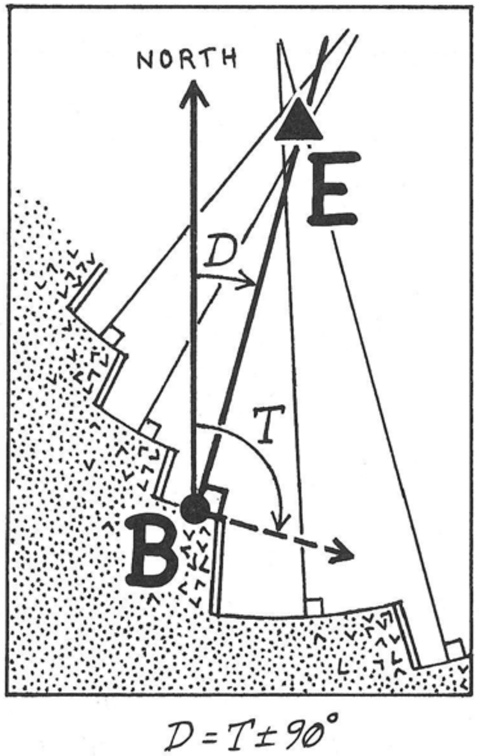


Figure 4-1.
Locating an Euler pole **E** from the trends *T* of transforms. Lines nearly intersecting at **E** are great circles perpendicular to the transforms.

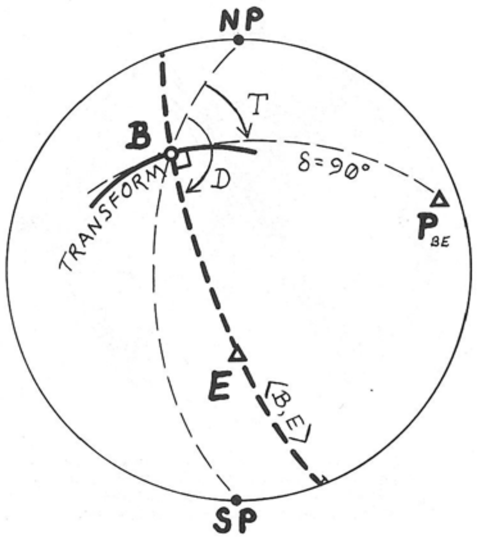


Figure 4-2.
Euler pole **E** is on the great circle perpendicular to the trend of the transform. $\mathbf{P}_{BE}$ is the pole of the great circle <**B**, **E**>.

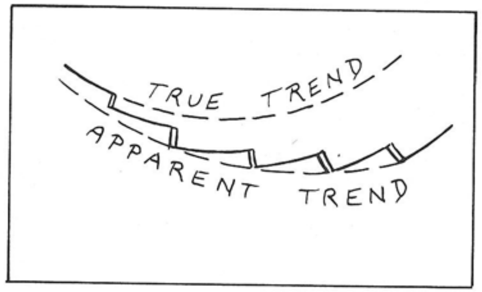
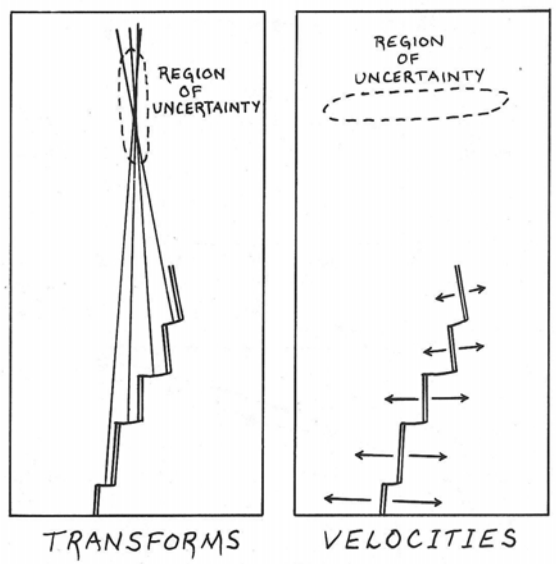


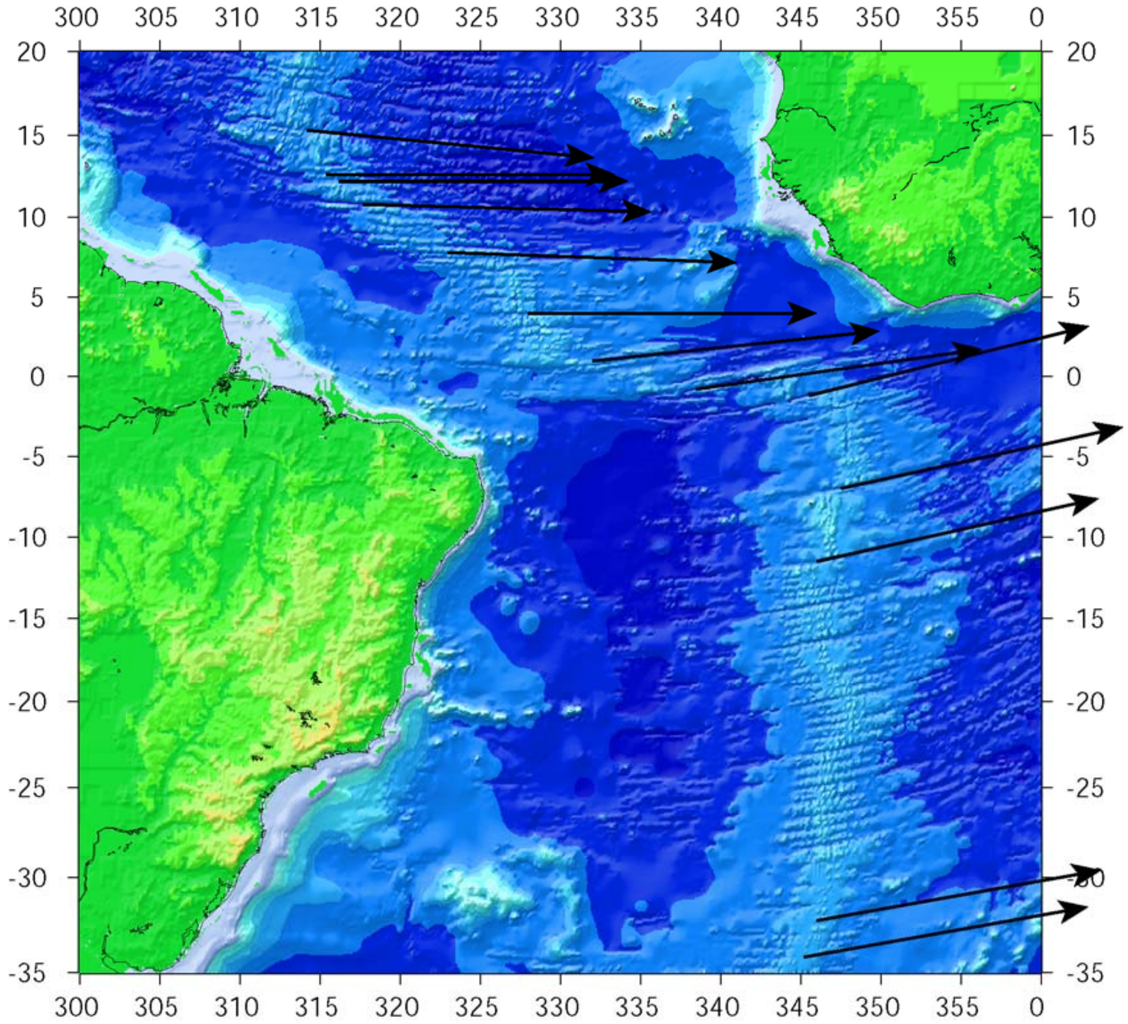
Figure 4-3.
Apparent and true trends of transform system offset by short ridge segments.



Geological model : real data

Transform faults azimuths

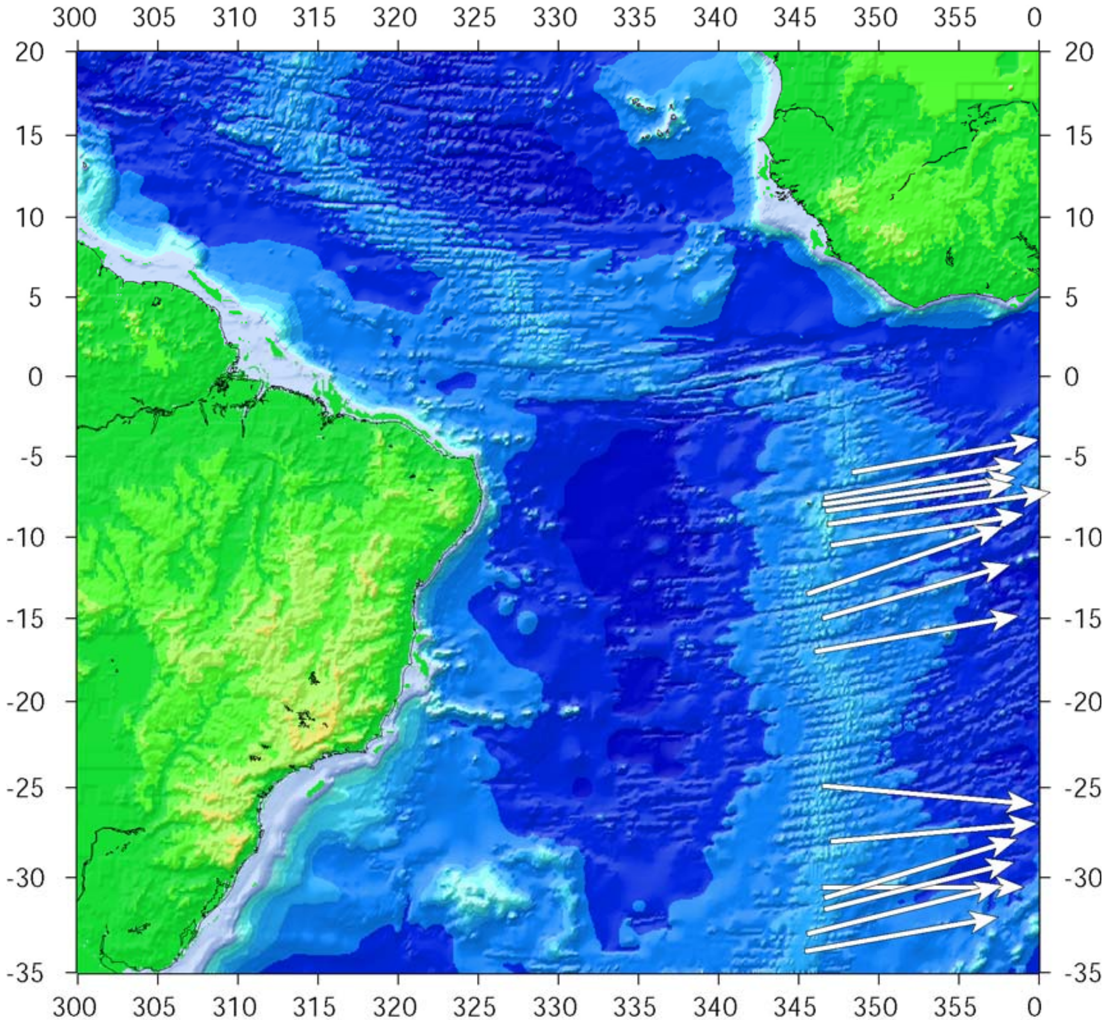
Lon	lat	azimuth
15.3	-45.8	95.5
12.6	-44.6	90.0
12.2	-43.8	90.0
10.8	-42.3	91.5
7.8	-37.0	92.0
4.0	-32.0	90.0
1.0	-28.0	84.0
-0.8	-21.5	82.0
-1.2	-14.5	76.0
-7.0	-12.5	77.7
-11.5	-14.0	77.5
-32.3	-14.0	80.0
-34.2	-14.8	80.0
-54.2	-2.0	65.0



Geological model : real data

Spreading rates

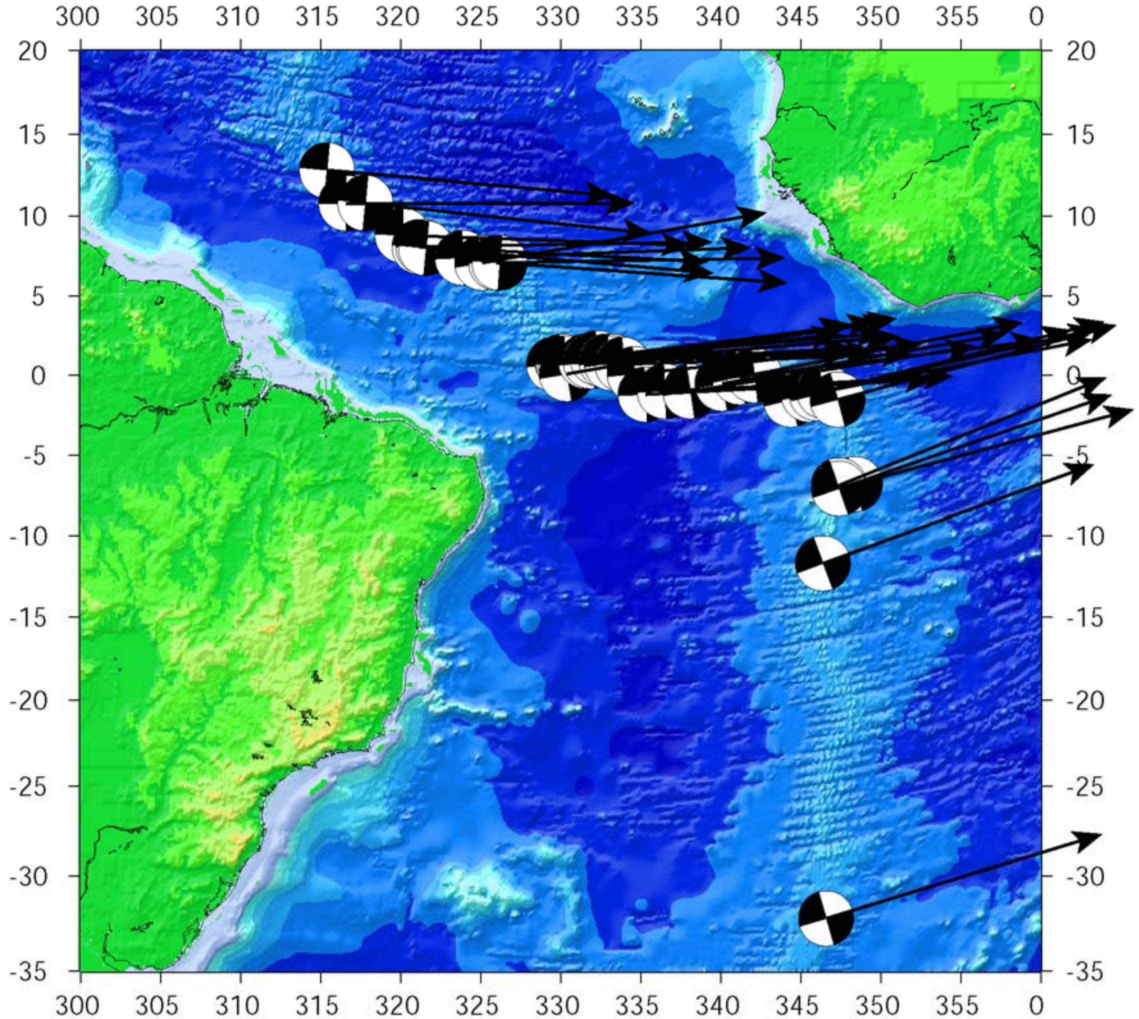
lon	lat	rate	az
-6.0	-11.7	33	10
-7.6	-13.4	35	10
-8.0	-13.5	34	8
-8.4	-13.3	33	8
-9.2	-13.2	39	8
-10.5	-13.0	34	9
-13.5	-14.5	36	19
-15.0	-13.5	34	16
-17.0	-14.0	36	10
-24.9	-13.5	37	-5
-28.0	-13.0	36	5
-30.5	-13.5	35	0
-31.1	-13.4	35	17
-31.7	-13.4	34	14
-33.0	-14.5	35	14
-33.9	-14.6	34	10
-38.5	-17.0	36	10
-40.0	-16.0	36	5
-42.0	-16.0	32	5
-43.0	-16.0	35	5
-54.2	-1.3	28	25
-54.5	-1.1	30	25



Geological model : real data
Slip vector azimuths

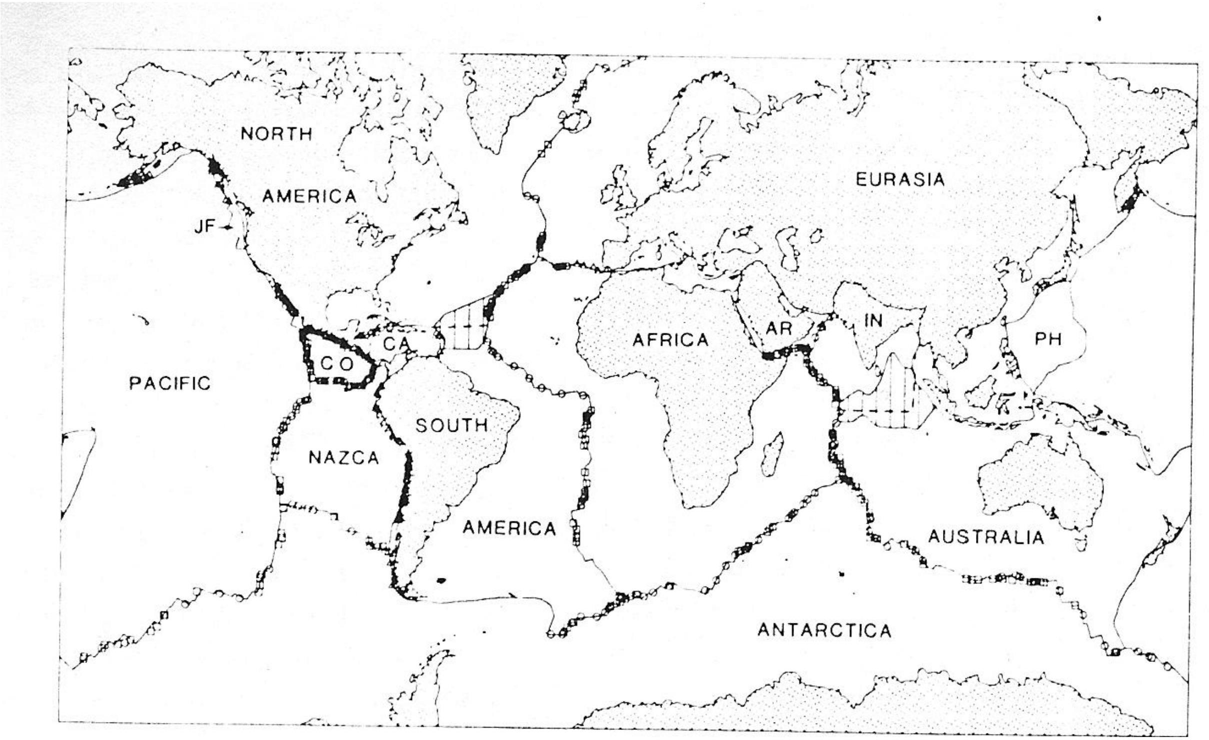
Lon	lat	azimut
12.8	-44.6	95.0
10.8	-43.4	90.0
10.8	-42.2	96.0
8.8	-39.9	92.0
8.1	-38.8	93.0
8.1	-38.5	89.0
8.0	-38.4	95.0
7.4	-36.1	88.0
7.1	-34.9	80.0
7.1	-34.0	89.0
7.1	-33.8	94.0
0.7	-30.4	84.0
0.9	-29.9	83.0
0.8	-29.8	88.0
0.8	-29.7	87.0
0.1	-29.6	80.0
0.9	-28.4	88.0
0.9	-28.1	82.0
1.1	-27.7	85.0
0.9	-27.1	85.0
0.9	-27.1	82.0
0.9	-26.8	85.0
0.8	-26.8	81.0
0.7	-26.1	88.0
0.1	-25.3	84.0
-1.2	-24.7	87.0
-1.0	-23.5	87.0
-1.0	-21.9	81.0

Lon	lat	azimut
-0.5	-19.9	80.0
-0.1	-18.8	79.0
-0.0	-17.9	83.0
-1.5	-15.6	76.0
-1.2	-14.5	79.0
-1.1	-14.0	77.0
-1.0	-13.5	76.0
-1.5	-12.7	75.0
-6.8	-11.6	75.0
-6.9	-12.6	68.0
-7.1	-12.6	71.0
-11.7	-13.6	70.0
-32.2	-13.4	73.0
-35.8	-16.0	76.0
-35.5	-16.1	81.0
-47.6	-12.9	76.0
-46.9	-10.8	85.0



Geological model : Nuvel-1A, Demets et al., 1990

Current plate motions, Geophys. Journal. Int., 101, 425-478, 1990



Around 1200 slip vector azimuth, transform fault orientations and spreading rates are compiled in one model for plate motion

Geological model : data table

Table 3. *(continued)*

26.90	-44.50	26	4	24.5	0.022	n16e	*Rabinowitz & Schouten* (1985)
26.20	-44.80	22	3	23.5	0.037	n30e	*McGregor et al.* (1977)
25.70	-45.00	24	4	24.2	0.022	n24e	*Rabinowitz & Schouten* (1985)
25.30	-45.40	22.5	2	24.4	0.089	n24e	*Rabinowitz & Schouten* (1985)
25.10	-45.40	24.5	2	24.4	0.090	n24e	*Rona & Gray* (1980)
24.50	-46.10	23	4	24.6	0.023	n23e	*Rabinowitz & Schouten* (1985)
24.20	-46.30	24.5	2	25.1	0.097	n15e	*Rona & Gray* (1980)
23.00	-45.00	25	4	25.2	0.025	n08e	*Rabinowitz & Schouten* (1985)
22.80	-45.00	25	2	25.1	0.100	n04e	*Rabinowitz & Schouten* (1985)

Africa-North America: Transform Azimuths

35.20	-35.60	104.5	2	103.6	0.203	*Roest et al.* (1984)
33.70	-38.70	104.5	2	103.4	0.216	*Roest et al.* (1984)
30.00	-42.40	101.5	3	102.9	0.100	*Roest et al.* (1984)
23.70	-45.70	98.0	2	102.2	0.220	*Roest et al.* (1984) & *Pockalny et al.* (1988)

Africa-North America: Slip Vectors

35.43	-36.03	102.0	20	103.6	0.002	CMT 4.29.85
35.41	-36.01	101.0	10	103.7	0.008	CMT 6.06.82
35.35	-36.08	100.0	10	103.7	0.008	*Bergman & Solomon* (1988)
35.14	-35.45	101.0	15	103.6	0.004	CMT 7.14.80
33.79	-38.64	101.0	10	103.4	0.009	*Bergman & Solomon* (1988)
33.78	-38.46	102.0	15	103.4	0.004	CMT 5.07.84
33.69	-38.60	103.0	15	103.4	0.004	CMT 5.03.84
28.74	-43.58	91.0	20	102.8	0.002	*Engeln et al.* (1986)
23.83	-45.94	100.0	10	102.2	0.009	*Bergman & Solomon* (1988)
23.86	-45.57	100.0	10	102.2	0.009	*Bergman & Solomon* (1988)
23.81	-45.44	106.0	15	102.2	0.004	CMT 11.28.81
23.74	-45.17	102.0	15	102.2	0.004	CMT 3.12.77

Africa-Eurasia: Transform Azimuths

36.90	-23.50	257.0	5	260.2	0.187	*Laughton et al.* (1972)
37.00	-22.60	265.0	3	263.3	0.399	*Laughton et al.* (1972)
37.10	-21.70	265.0	3	266.3	0.384	*Laughton et al.* (1972)
37.10	-20.50	-90.0	7	270.4	0.098	*Laughton et al.* (1972)

Africa-Eurasia: Slip Vectors

37.75	-17.25	-89.0	25	-79.2	0.022	CMT 10.17.83
37.22	-14.93	-50.0	25	-71.5	0.042	*Grimison & Chen* (1986)
36.96	-11.84	267.0	25	-62.0	0.066	*Grimison & Chen* (1986)
36.01	-10.57	-35.0	25	-57.0	0.092	*Fukao* (1973)
35.99	-10.34	-60.0	25	-56.3	0.098	*Grimison & Chen* (1986)
36.23	-7.61	-35.0	25	-49.8	0.104	*Grimison & Chen* (1986)

Africa-South America: Spreading Rates

-6.00	-11.70	33	6	34.1	0.018	n10w	*van Andel et al.* (1973)
-7.60	-13.40	35	6	34.4	0.018	n10w	*van Andel et al.* (1973)
-8.00	-13.50	34	2	34.4	0.160	n08w	*Brozena* (1986)
-8.40	-13.30	33	6	34.5	0.018	n08w	*van Andel et al.* (1973)
-9.20	-13.20	39	6	34.6	0.017	n08w	*van Andel et al.* (1973)
-10.50	-13.00	34	3	34.8	0.068	n09w	*Brozena* (1986)
-13.50	-14.50	36	4	35.0	0.034	n19w	*Brozena* (1986)
-15.00	-13.50	34	2	35.4	0.136	n16w	*Brozena* (1986)
-17.00	-14.00	36	3	35.6	0.061	n10w	*Brozena* (1986)
-24.90	-13.50	37	6	34.5	0.013	n05e	*Dickson et al.* (1968)
-28.00	-13.00	36	3	35.7	0.053	n05w	*Dickson et al.* (1968)
-30.50	-13.50	35	3	35.1	0.051	n00e	*Dickson et al.* (1968)
-31.10	-13.40	35	5	35.7	0.019	n17w	*Welch et al.* (1986)
-31.70	-13.40	34	3	35.7	0.052	n14w	*Welch et al.* (1986)
-33.00	-14.50	35	3	35.6	0.051	n14w	*Welch et al.* (1986)
-33.90	-14.60	34	4	35.6	0.029	n10w	*Welch et al.* (1986)
-38.50	-17.00	36	6	35.1	0.013	n10w	*Dickson et al.* (1968)
-40.00	-16.00	36	3	34.7	0.051	n05w	*Loomis & Morgan* (1973)
-42.00	-16.00	32	4	34.4	0.029	n05w	*Dickson et al.* (1968)
-43.00	-16.00	35	3	34.2	0.052	n05w	*Loomis & Morgan* (1973)
-54.20	-1.30	28	5	30.9	0.023	n25w	NGDC *Chain* 115-4
-54.50	-1.10	30	3	30.8	0.064	n25w	NGDC *Chain* 115-4
-54.60	-1.00	30	5	30.8	0.023	n25w	NGDC *Chain* 115-4

Africa-South America: Transform Azimuths

15.30	-45.80	95.5	3	94.0	0.128	*Roest et al.* (1984)
12.60	-44.60	90.0	3	93.1	0.108	*Collette et al.* (1979)
12.20	-43.80	90.0	3	92.6	0.101	*Collette et al.* (1979)
10.80	-42.30	91.5	2	91.7	0.197	*Macdonald et al.* (1986)
7.80	-37.00	92.0	8	88.6	0.008	*Emery & Uchupi* (1984)
4.00	-32.00	90.0	5	86.0	0.016	*Emery & Uchupi* (1984)
1.00	-28.00	84.0	5	84.1	0.015	*Emery & Uchupi* (1984)
-0.80	-21.50	82.0	2	81.0	0.110	*Belderson et al.* (1984)
-1.20	-14.50	76.0	3	77.8	0.069	*Emery & Uchupi* (1985)
-7.00	-12.50	77.7	2	77.3	0.150	*Brozena* (1986)
-11.50	-14.00	77.5	3	78.2	0.056	*Brozena* (1986)
-32.30	-14.00	80.0	2	78.5	0.098	D. Forsyth (personal communication, 1985)
-34.20	-14.80	80.0	3	78.8	0.042	D. Forsyth (personal communication, 1985)
-54.20	-2.00	65.0	10	71.0	0.006	*Sclater et al.* (1976a)

Africa-South America: Slip Vectors

15.34	-45.92	97.0	10	94.1	0.012	*Bergman & Solomon* (1988)
15.30	-45.78	98.0	10	94.0	0.011	*Bergman & Solomon* (1988)
15.25	-45.15	97.0	10	93.6	0.011	*Bergman & Solomon* (1988)
14.14	-45.18	100.0	20	93.6	0.003	*Engeln et al.* (1986)
12.84	-44.57	95.0	15	93.1	0.004	CMT 6.09.87
12.05	-43.79	101.0	20	92.6	0.002	*Engeln et al.* (1986)
10.79	-43.51	92.0	10	92.4	0.009	*Bergman & Solomon* (1988)
10.83	-43.43	90.0	10	92.4	0.008	CMT 1.10.85
10.83	-43.23	96.0	20	92.2	0.002	*Engeln et al.* (1986)
10.77	-43.11	92.0	10	92.2	0.008	*Bergman & Solomon* (1988)
10.79	-42.23	96.0	15	91.7	0.003	CMT 3.20.84
10.72	-42.02	97.0	20	91.5	0.002	*Engeln et al.* (1986)
10.72	-41.68	87.0	10	91.3	0.008	*Bergman & Solomon* (1988)
8.80	-39.87	92.0	15	90.3	0.003	CMT 8.13.80
8.05	-38.79	102.0	20	89.6	0.001	*Engeln et al.* (1986)
8.15	-38.76	93.0	10	89.6	0.006	CMT 11.01.84
8.10	-38.55	89.0	15	89.5	0.003	CMT 11.05.78
8.04	-38.39	95.0	15	89.4	0.003	CMT 12.06.81
8.11	-38.09	90.0	10	89.3	0.006	*Engeln et al.* (1986)
7.39	-36.10	88.0	15	88.1	0.002	CMT 4.22.81
7.30	-34.86	85.0	10	87.4	0.005	*Engeln et al.* (1986)
7.08	-34.87	80.0	15	87.5	0.002	CMT 12.24.85
7.10	-34.04	89.0	15	87.0	0.002	CMT 7.26.80
7.07	-33.85	94.0	20	86.9	0.001	CMT 8.30.84
0.67	-30.39	84.0	15	85.3	0.002	CMT 6.22.84
0.86	-29.88	83.0	10	85.0	0.004	CMT 10.12.85
0.83	-29.82	88.0	10	85.0	0.004	CMT 3.20.78
0.77	-29.69	87.0	10	84.9	0.004	CMT 3.20.78
0.11	-29.60	80.0	20	84.9	0.001	CMT 7.24.80
0.82	-28.98	90.0	20	84.6	0.001	*Engeln et al.* (1986)
0.95	-28.43	88.0	10	84.3	0.004	CMT 6.06.85
0.97	-28.29	89.0	20	84.2	0.001	*Engeln et al.* (1986)
0.93	-28.09	82.0	15	84.1	0.002	CMT 9.19.84
1.14	-27.71	85.0	15	83.9	0.002	CMT 6.22.78
0.89	-27.11	85.0	15	83.6	0.002	CMT 11.14.79
0.95	-27.08	82.0	15	83.6	0.002	CMT 11.02.81
0.93	-26.83	85.0	15	83.5	0.002	CMT 7.01.85
0.80	-26.77	81.0	15	83.5	0.002	CMT 6.15.86
0.90	-26.77	88.0	20	83.4	0.001	*Engeln et al.* (1986)
0.87	-26.50	88.0	20	83.3	0.001	*Engeln et al.* (1986)
0.75	-26.14	88.0	20	83.1	0.001	CMT 3.23.86
0.81	-25.45	89.0	20	82.8	0.001	*Engeln et al.* (1986)
0.11	-25.35	84.0	10	82.8	0.004	CMT 11.01.80
-1.19	-24.68	87.0	10	82.5	0.004	CMT 8.12.82
-1.30	-24.30	99.0	20	82.4	0.001	*Engeln et al.* (1986)
-0.99	-23.48	87.0	15	81.9	0.002	CMT 12.08.84
-0.85	-22.13	85.0	20	81.3	0.001	*Engeln et al.* (1986)
-0.97	-21.86	81.0	10	81.2	0.004	CMT 1.03.82
-0.84	-21.81	77.0	10	81.1	0.004	CMT 10.13.83
-0.51	-19.92	80.0	15	80.2	0.002	CMT 12.29.86
-0.50	-19.90	80.0	20	80.2	0.001	*Engeln et al.* (1986)
-0.52	-19.86	77.0	10	80.2	0.005	CMT 4.22.84
-0.58	-19.77	83.0	15	80.1	0.002	CMT 10.09.84
-0.38	-19.55	80.0	15	80.0	0.002	CMT 6.04.85
-0.22	-19.19	79.0	15	79.8	0.002	CMT 6.07.87
-0.32	-19.17	83.0	20	79.8	0.001	*Engeln et al.* (1986)
-0.04	-19.14	77.0	10	79.8	0.005	CMT 5.05.87
-0.13	-18.83	79.0	10	79.6	0.005	CMT 7.07.81
-0.30	-18.60	88.0	20	79.6	0.001	*Engeln et al.* (1986)
-0.14	-18.24	74.0	15	79.4	0.002	CMT 3.12.87
-0.19	-18.03	89.0	20	79.3	0.001	*Engeln et al.* (1986)
-0.02	-17.88	83.0	10	79.2	0.005	CMT 6.24.86

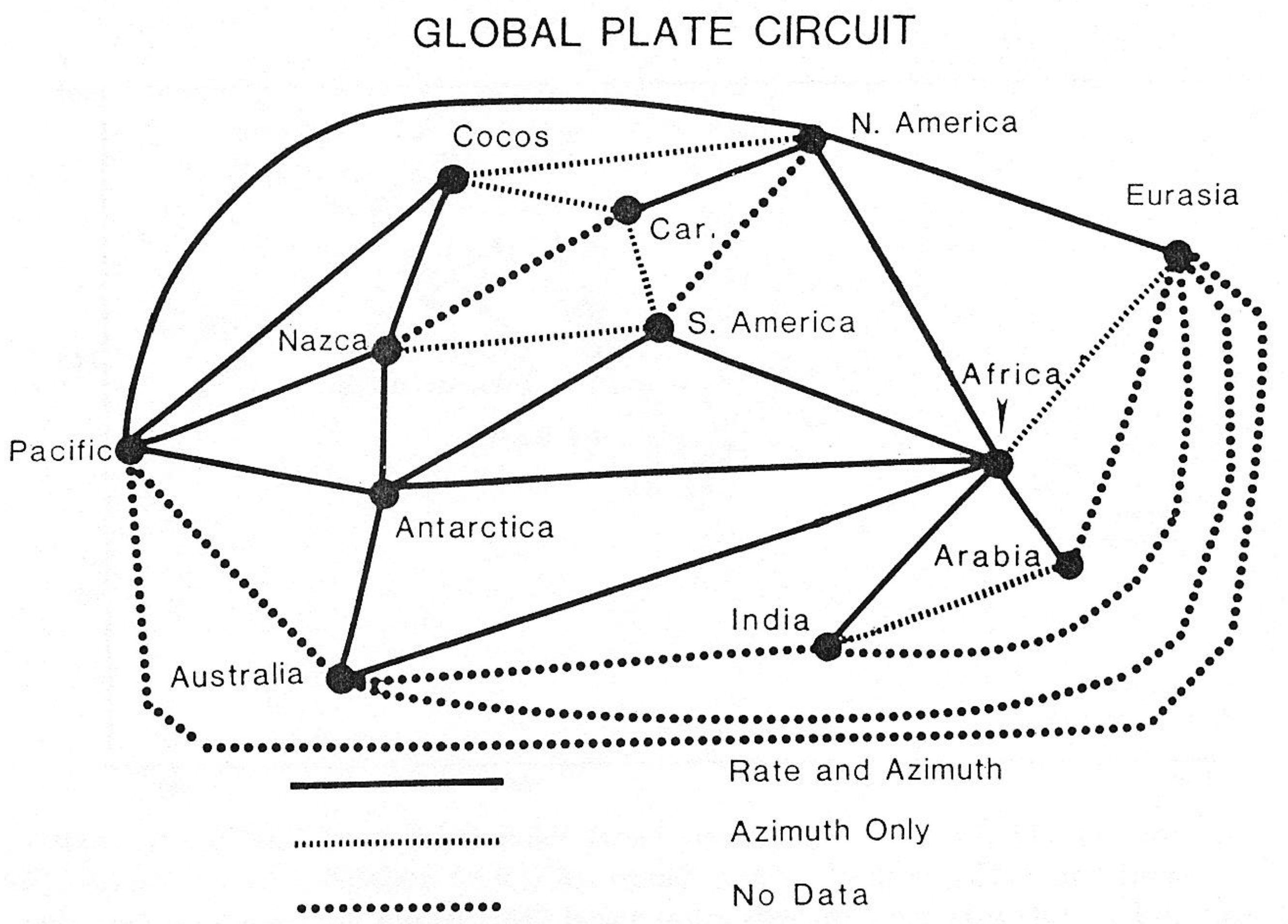
Arabia-India: Fault Trends

21.00	61.80	30.0	5	27.8	0.459	*Matthews* (1966)
18.00	60.20	23.0	5	22.3	0.534	*Matthews* (1966)

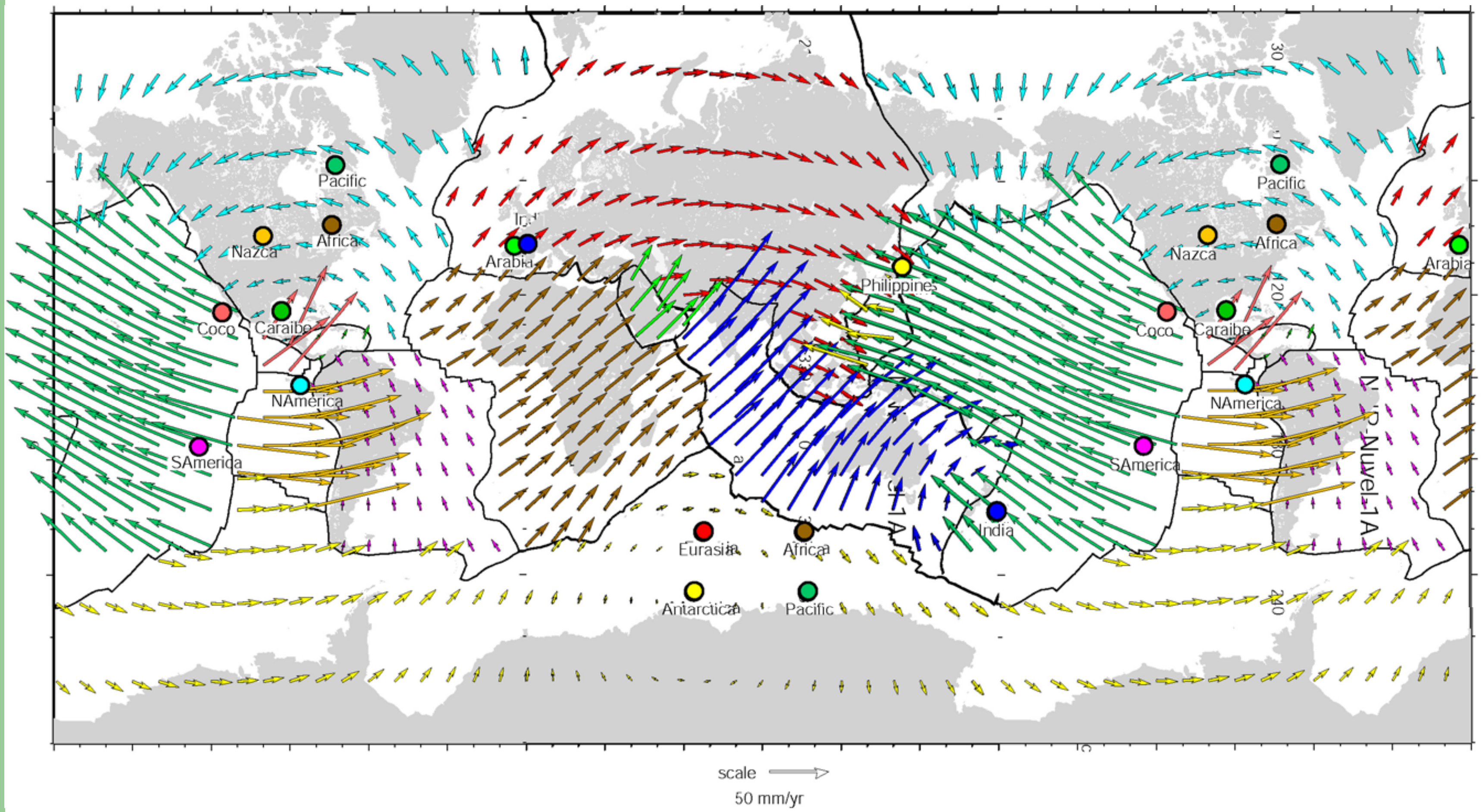
Arabia-India: Slip Vectors

24.58	66.23	41.0	15	37.5	0.270	*Quittmeyer & Kafka* (1984)
23.79	64.73	28.0	15	34.6	0.176	*Quittmeyer & Kafka* (1984)
21.87	62.32	12.0	15	29.5	0.067	*Quittmeyer & Kafka* (1984)
20.91	62.44	26.0	15	28.3	0.055	CMT 4.7.85
14.94	57.96	23.0	15	16.4	0.171	CMT 12.14.85
14.57	58.09	10.0	15	16.0	0.188	CMT 12.5.81

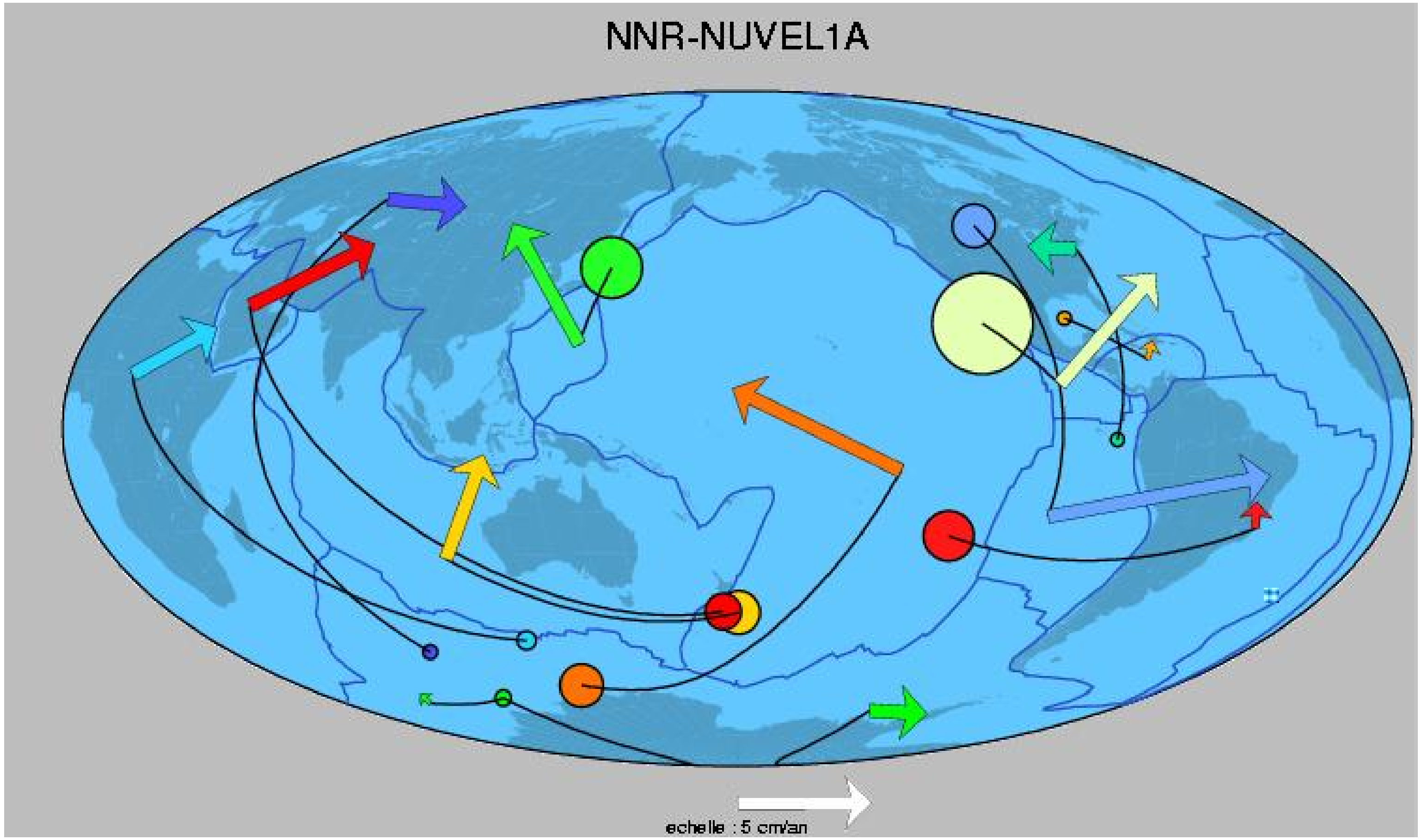
Geological model : closure circuit



NNR-Nuvel-1A : velocities

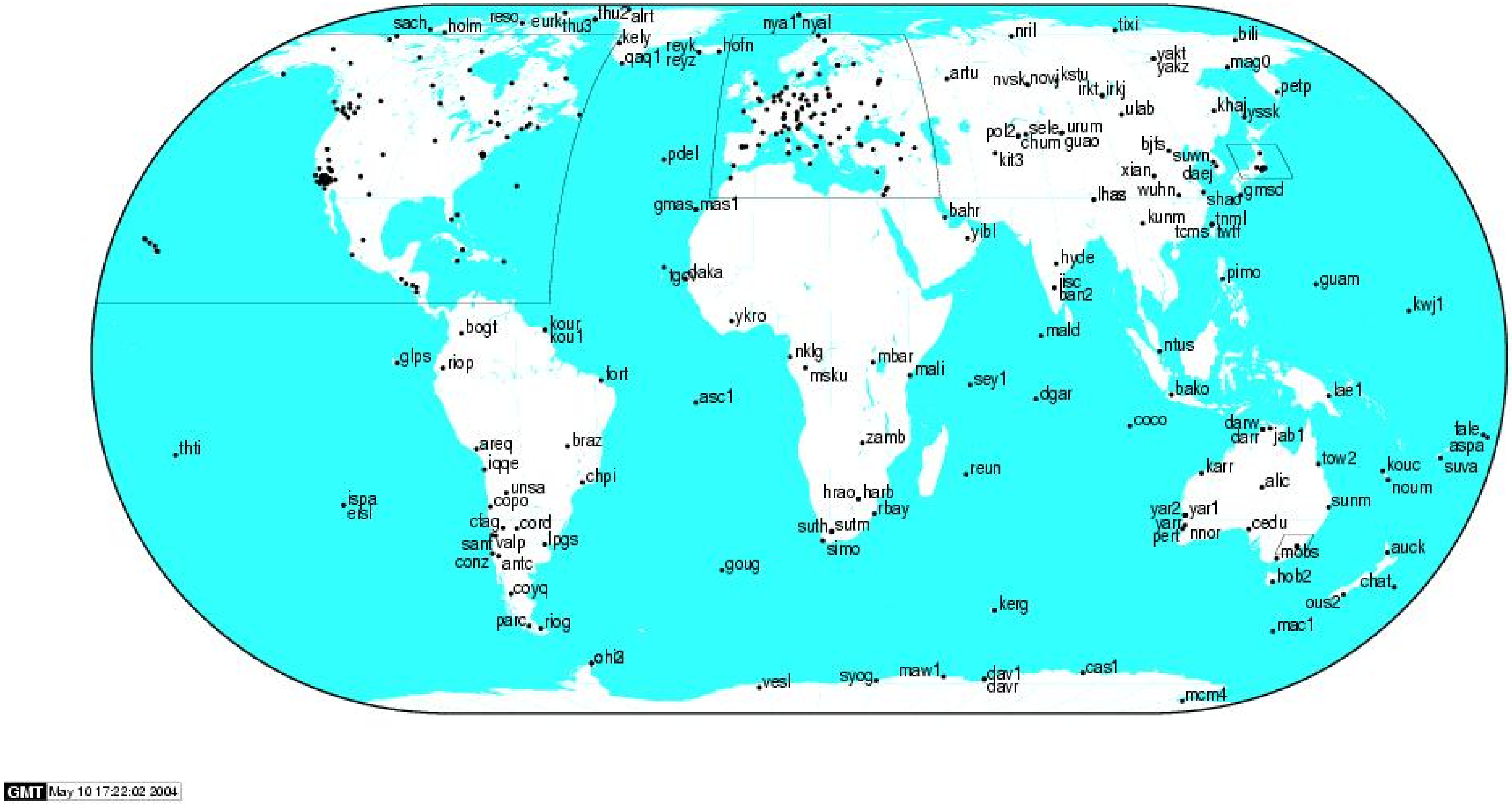


NNR-Nuvel-1A : poles

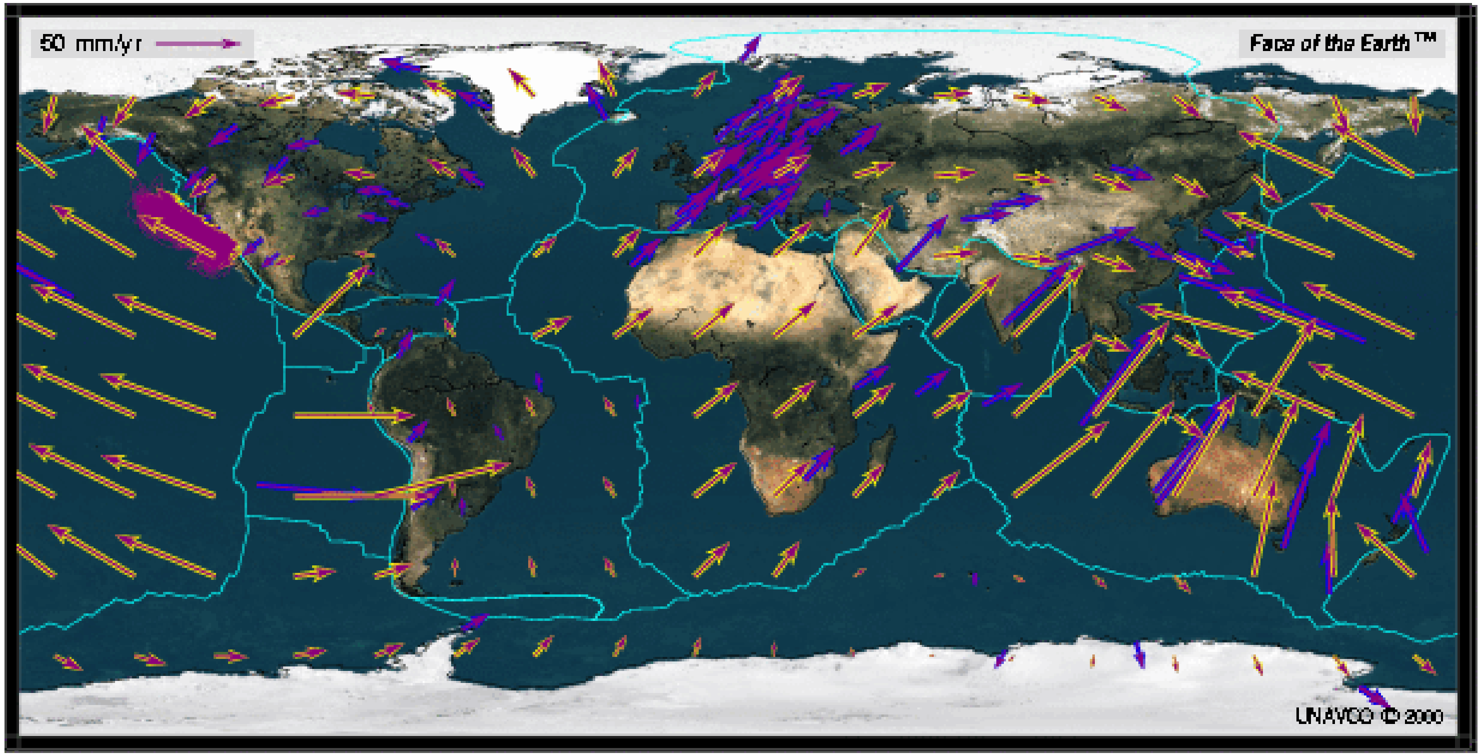


IGS network

IGS Tracking Network : http://igscb.jpl.nasa.gov

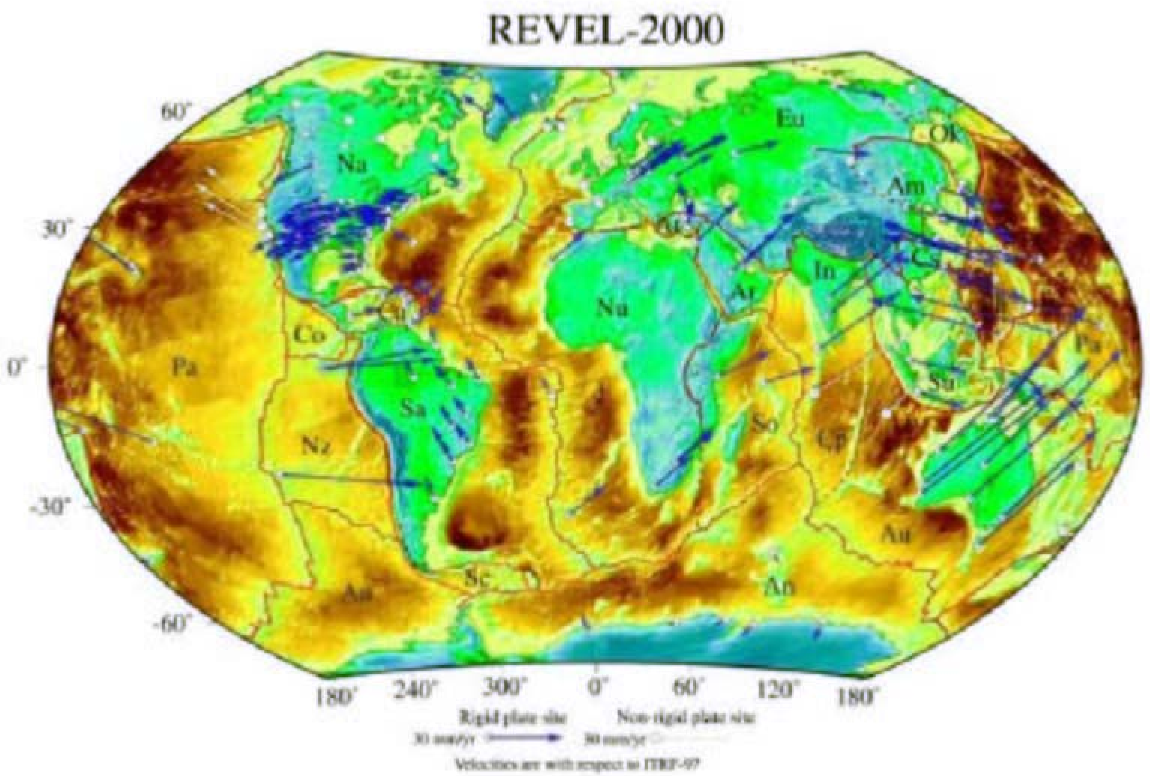


GPS VEL solution

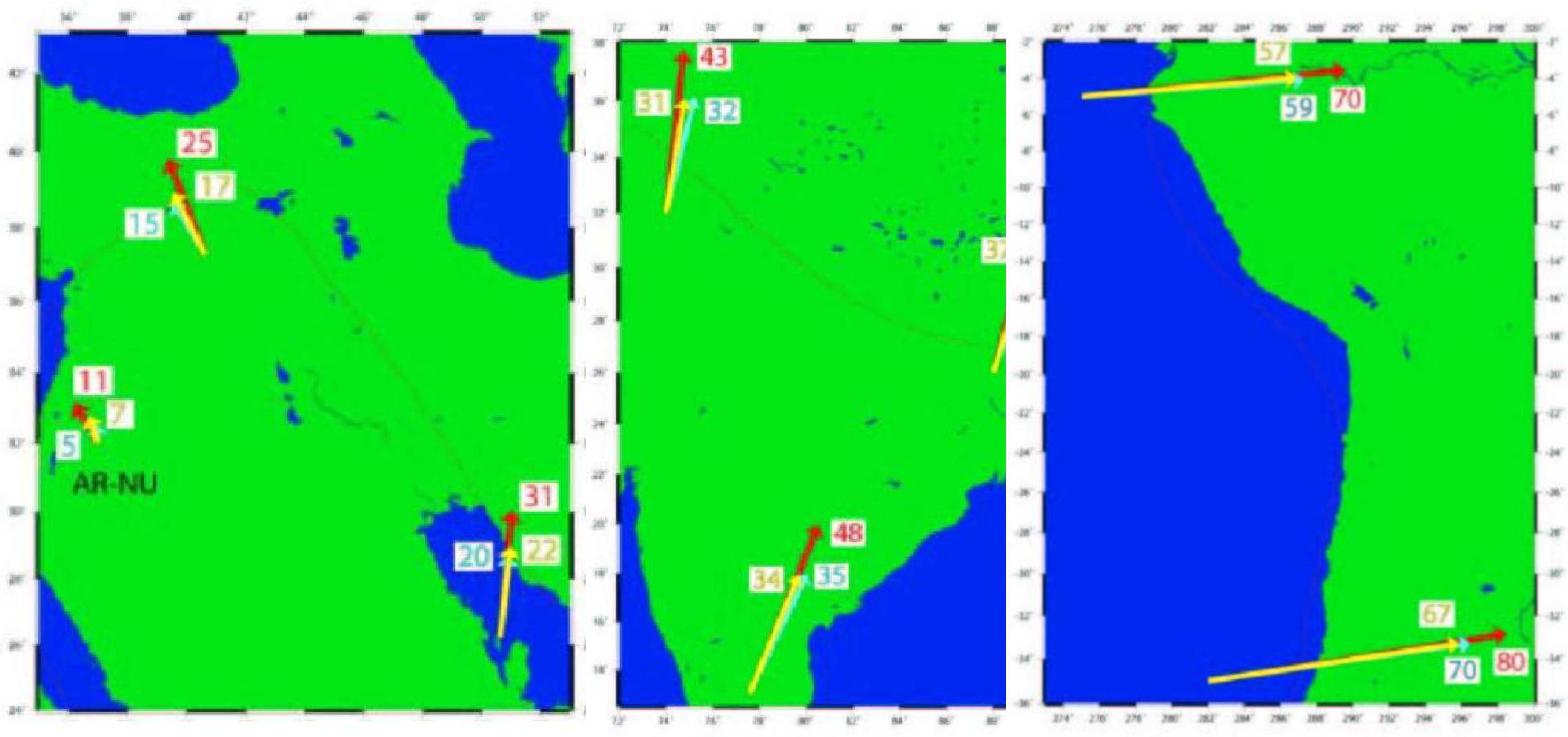


Nuvel-1A (yellow) – GPSVEL (violet)

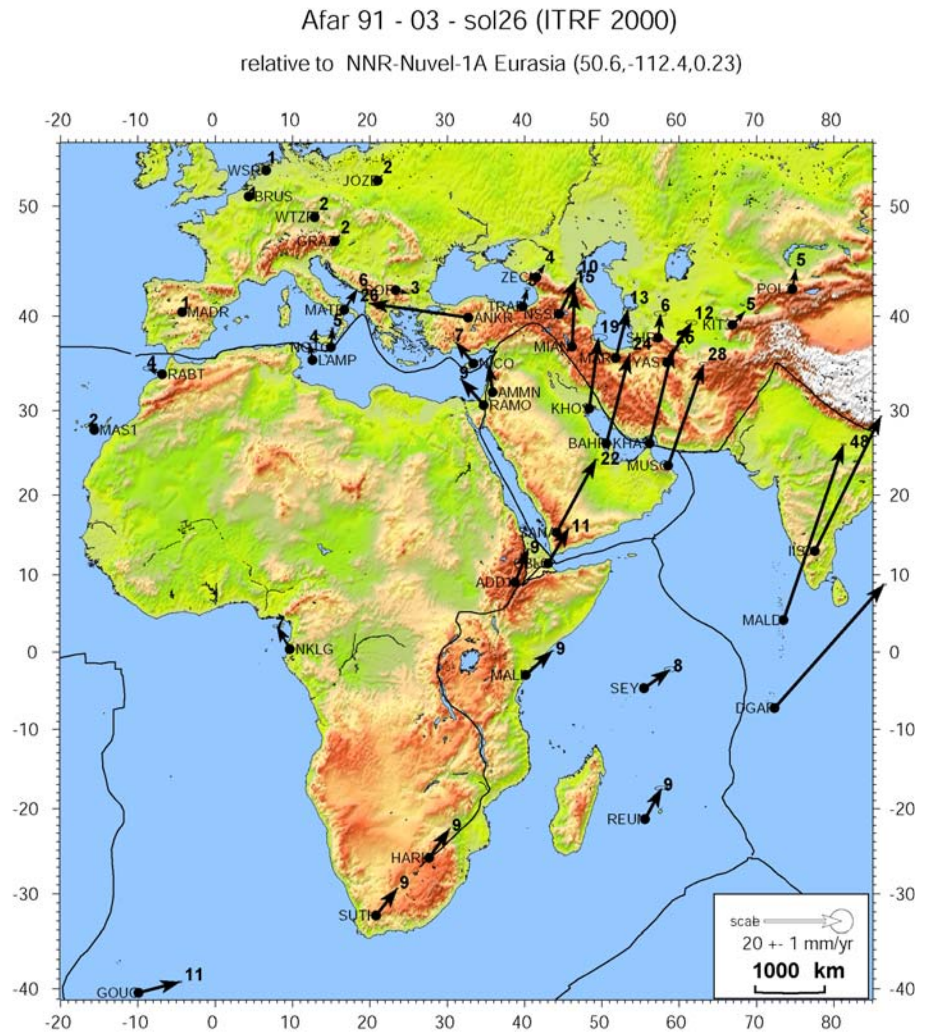
Revel Stella et al 2002 (ITRF97)



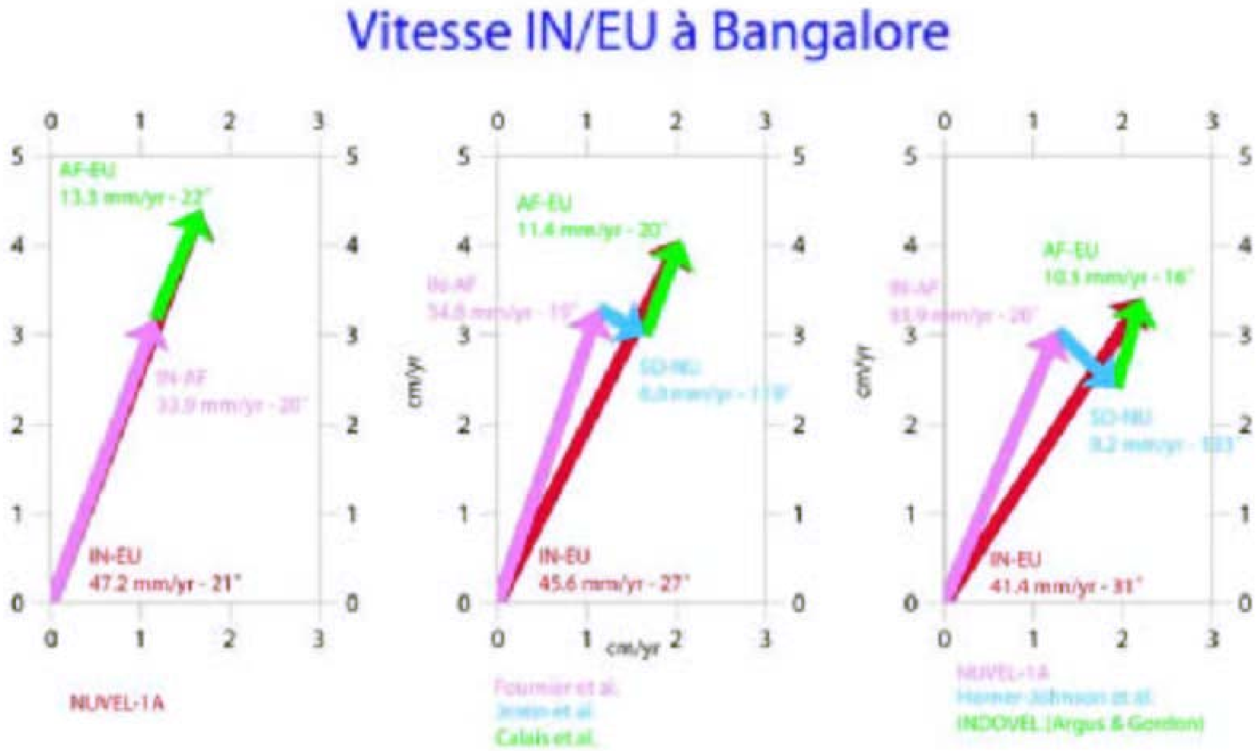
GPS finds Arabia, India and Nazca are slower



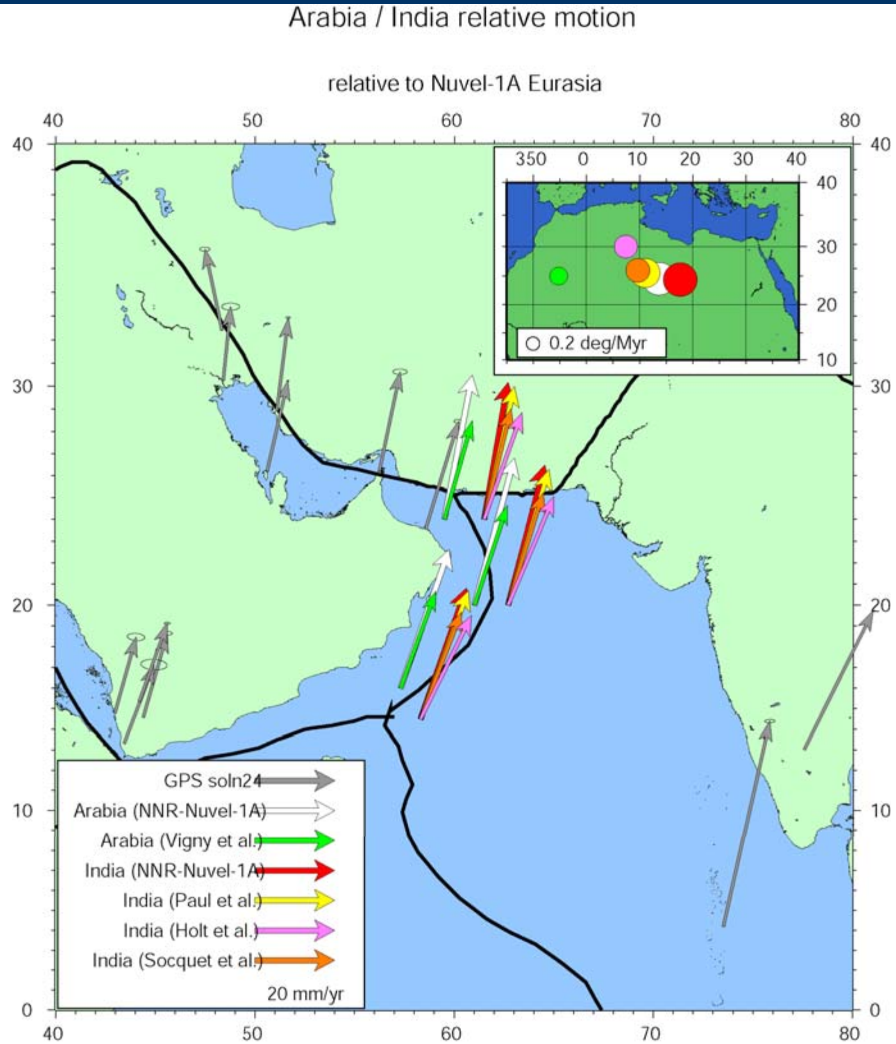
Africa Arabia India solution



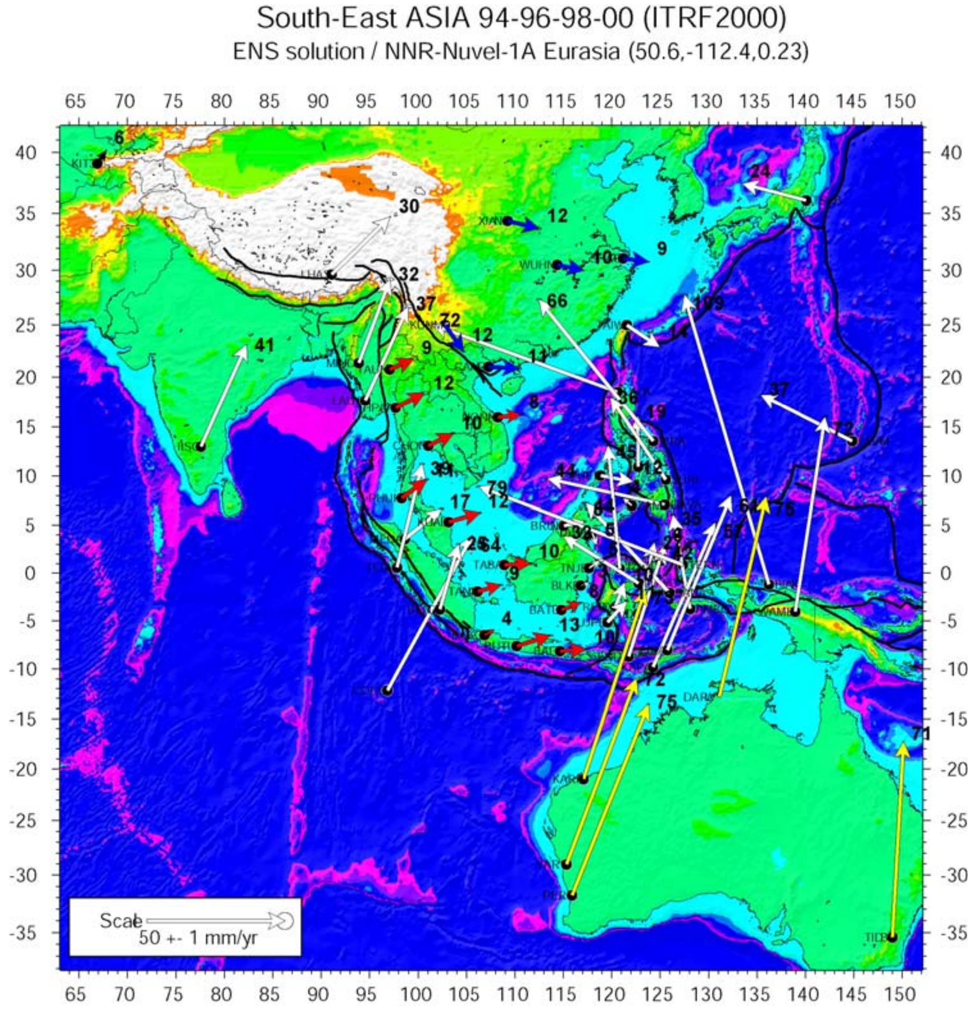
India-Africa-Somalia-Eurasia velocity composition



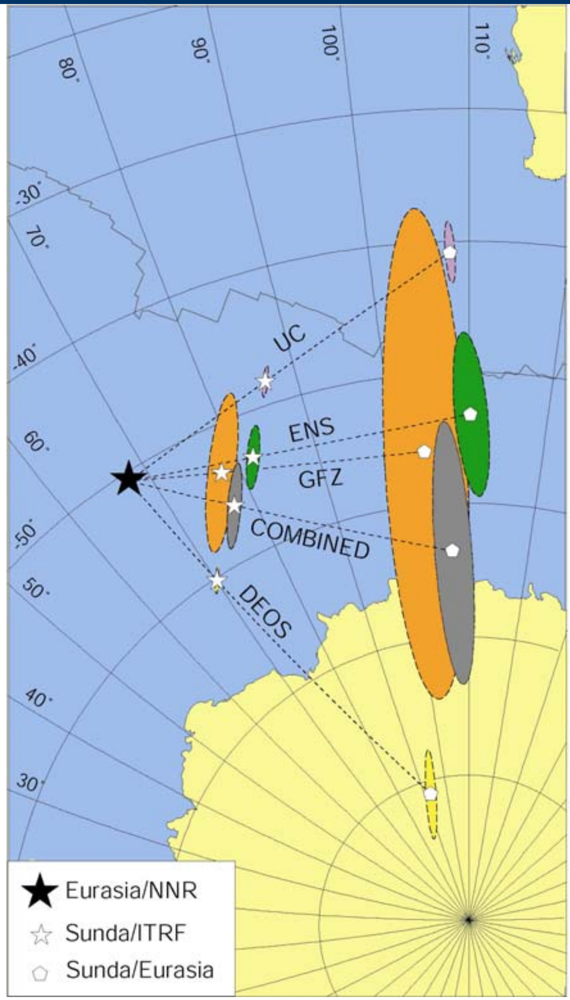
Arabia India relative motion

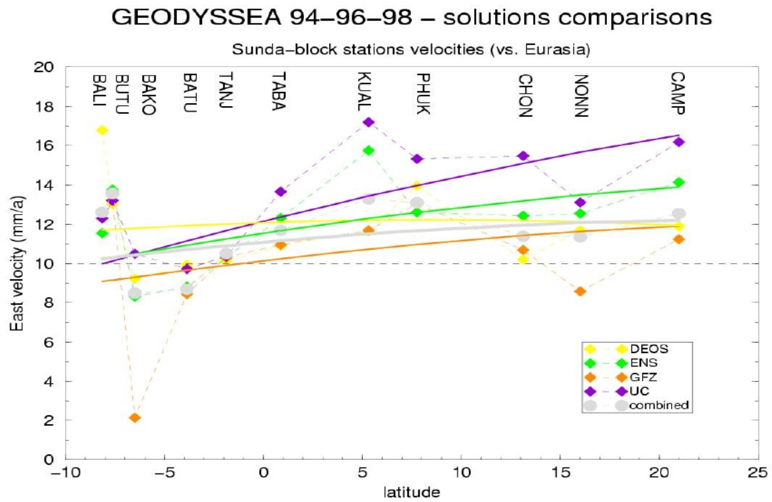


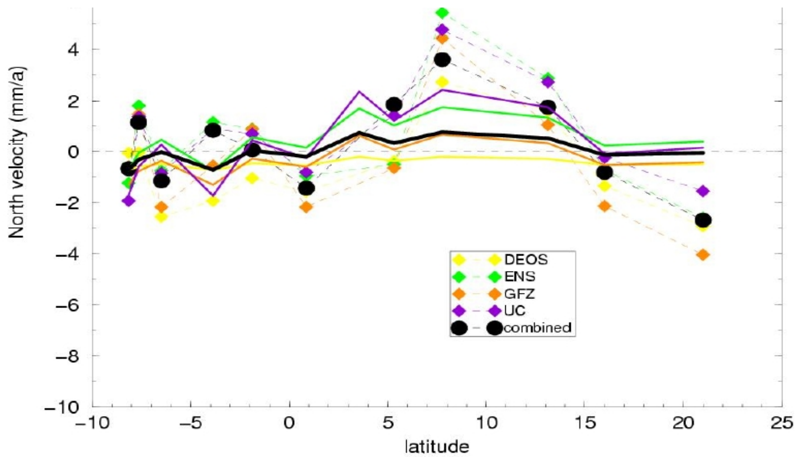
Rigid Sundaland



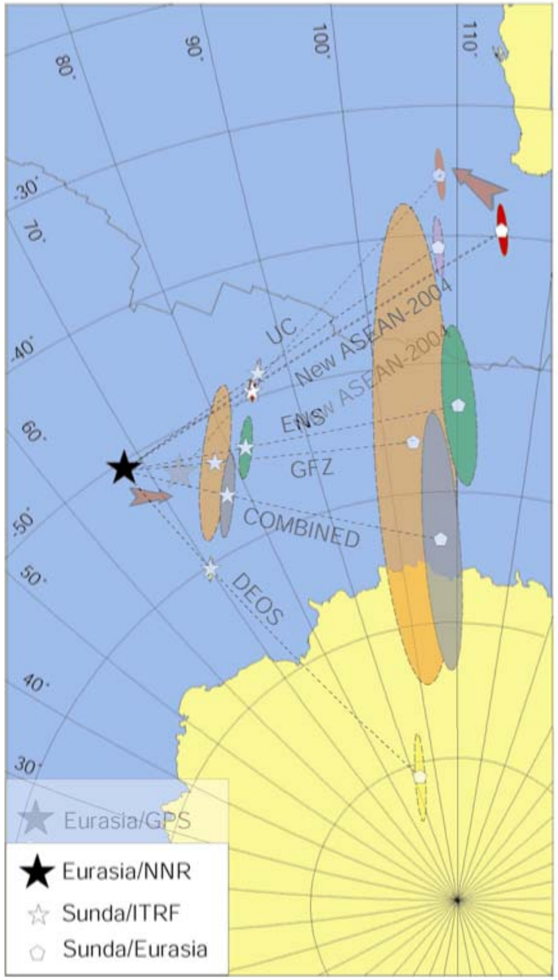
GEODYSSEA poles

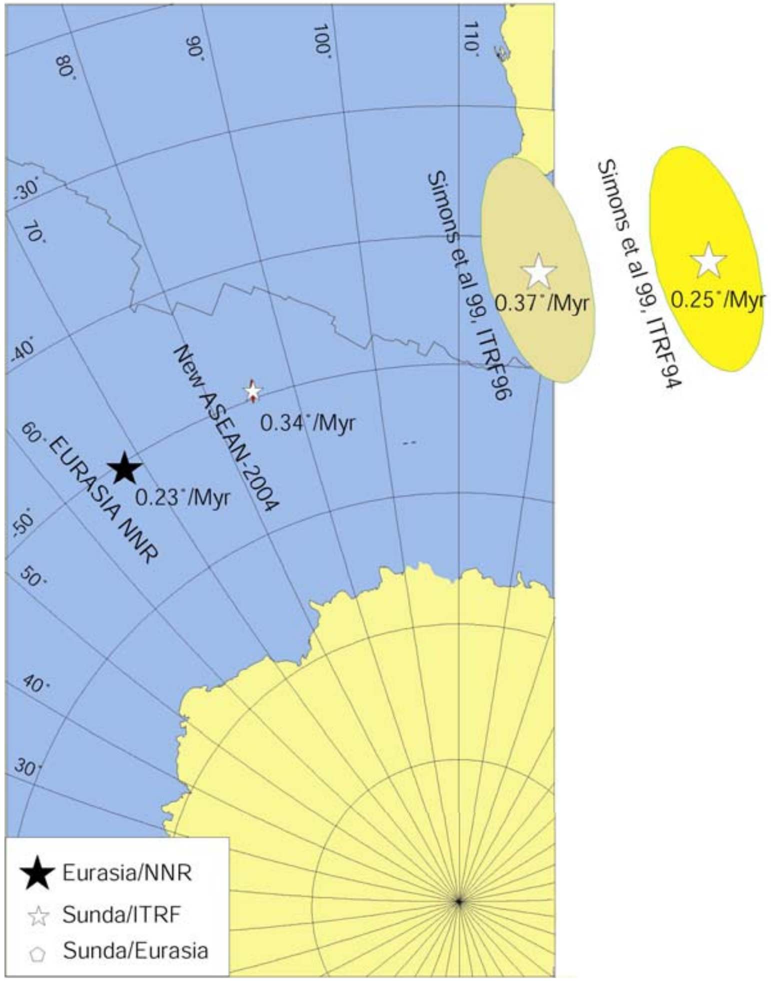




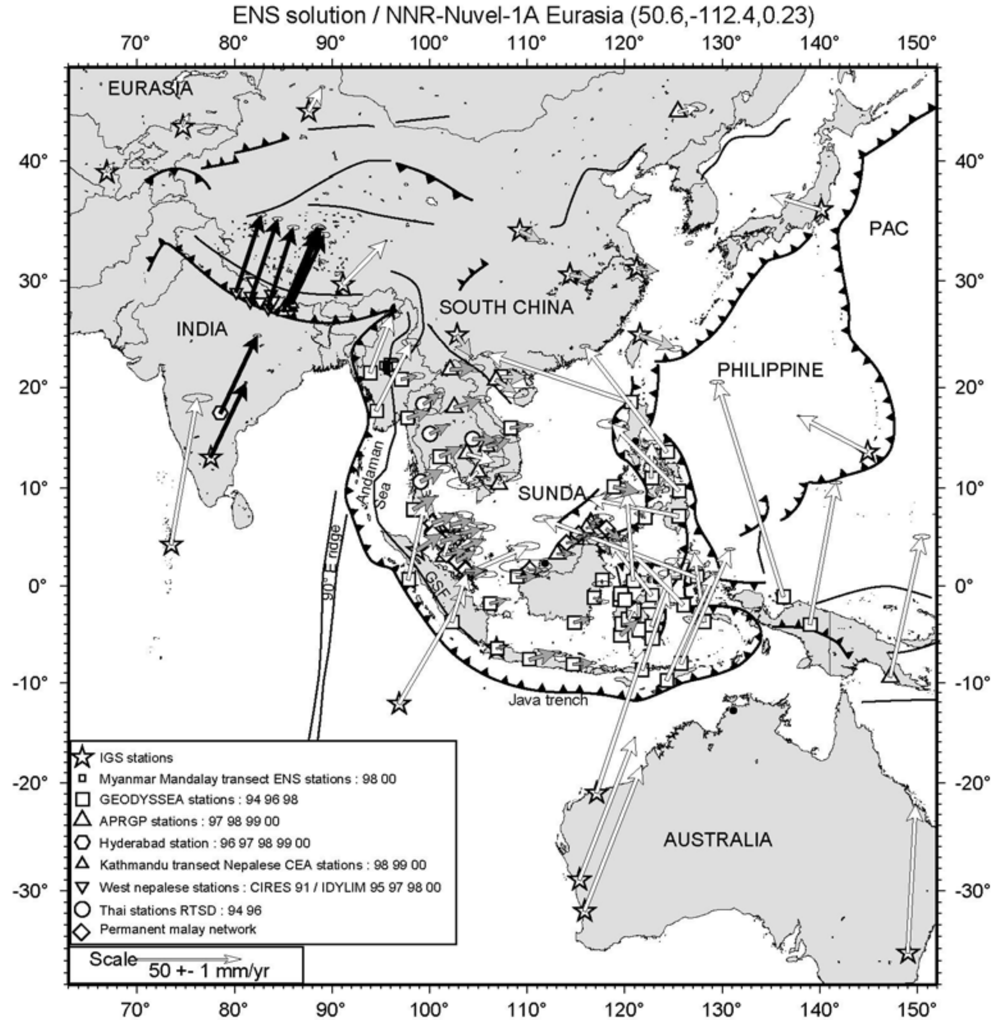


Older GEODYSSEA poles



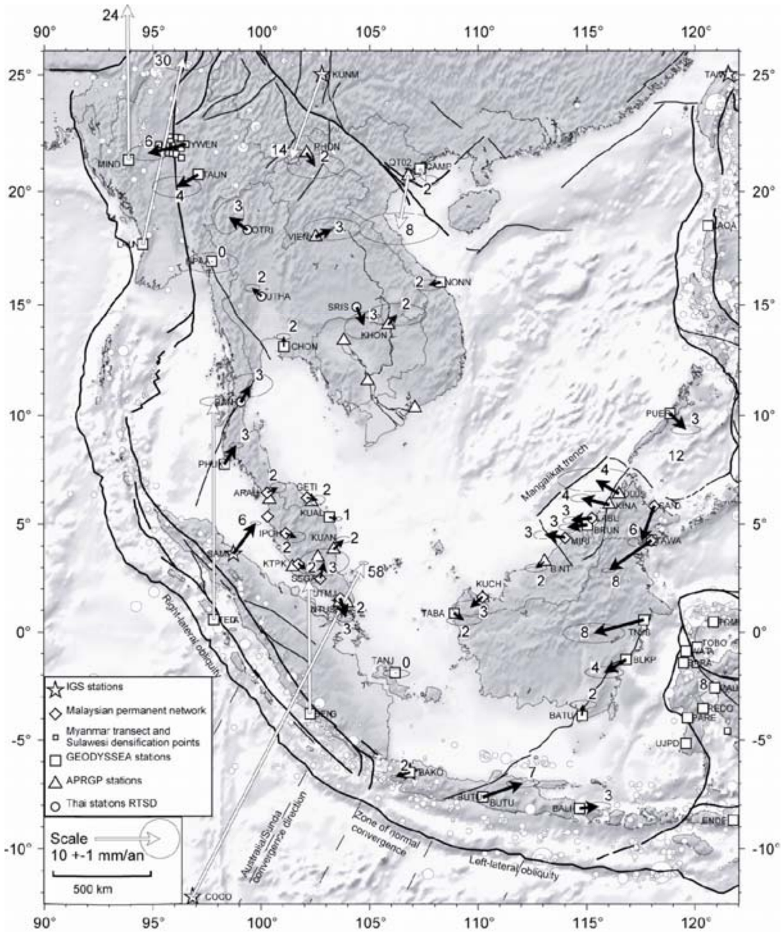


New ASEAN solution (Simons and Socquet, submitted)

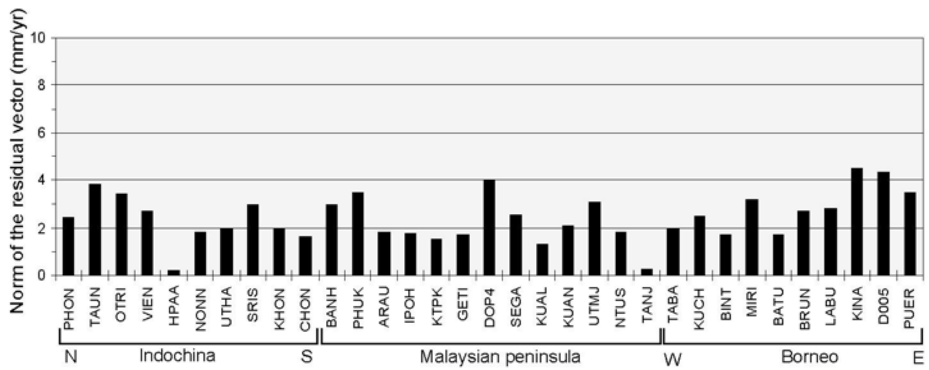


ASEAN Residual velocities

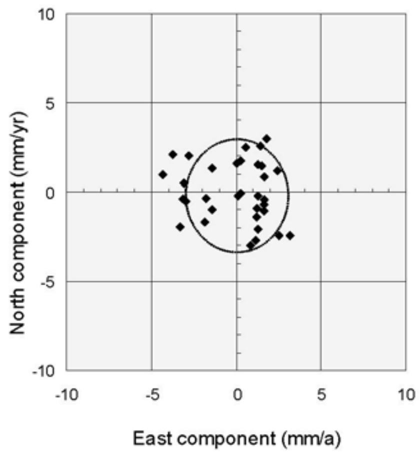
Pole positions don't matter … Only residual velocities do



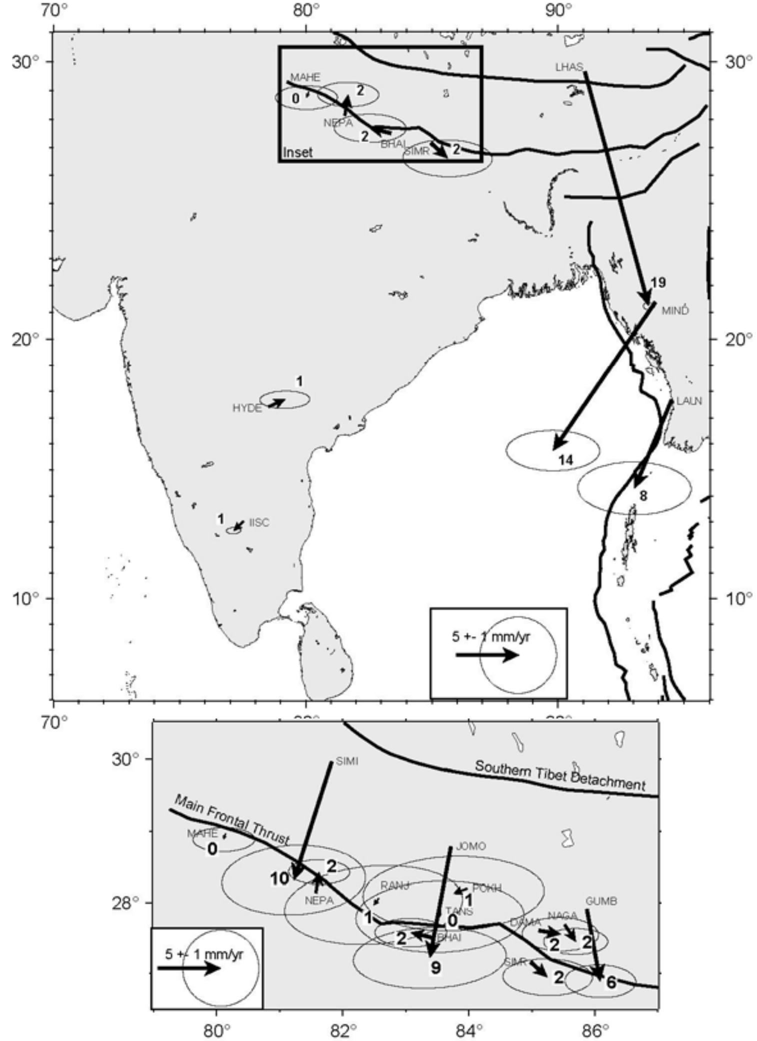
BEST FIT RESIDUALS

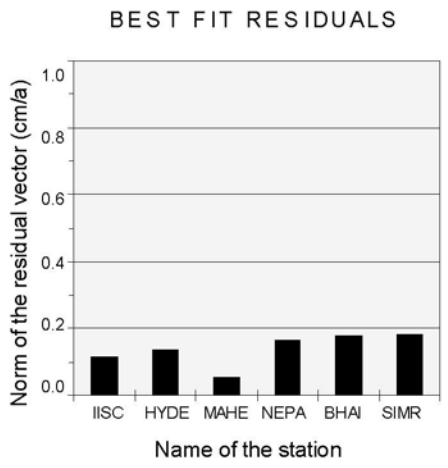


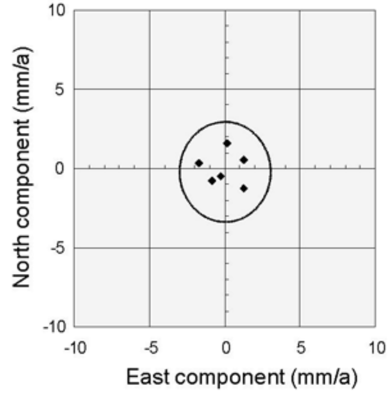
RESIDUAL VECTOR COMPONENTS



Indian residual velocities

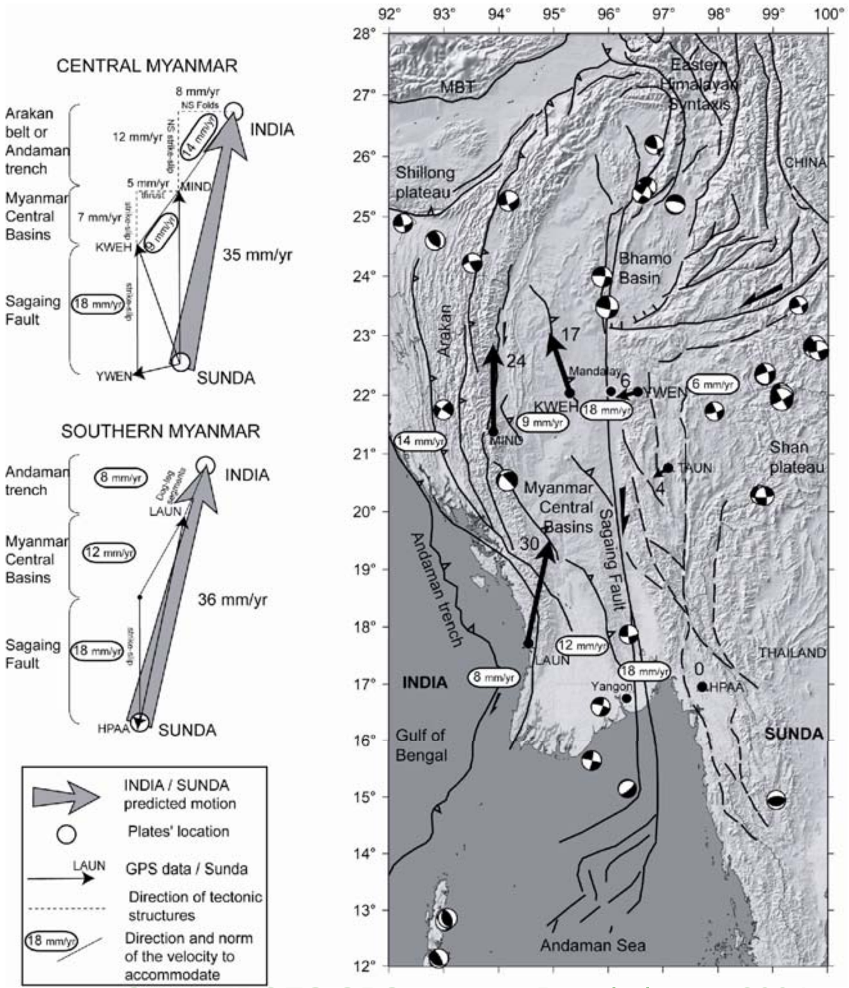






India/Sunda relative motion

Pole positions don't matter….only predicted motions on plate boundary do



Strain rate and rotation rate tensors (1)

To asses plate deformation :

1. Look at station velocity residuals
2. Compute strain rate and rotation rate tensors

$$\text{Strain} = \frac{\text{Velocity}}{\text{Distance}} = \frac{\text{mm/yr}}{\text{km}} = \text{\% / yr}$$

$$\text{Matrix tensor notation : } S_i^j = d(V_i) / d(x_j) = \begin{vmatrix} d(V_x) / d(x) & d(V_x) / d(y) \\ d(V_y) / d(x) & d(V_y) / d(y) \end{vmatrix}$$

Theory says : [S] = [E] + [W]

	[E]	[W]
	Symetrical	Antisymetrical
	Strain rate	rotation rate

Strain rate and rotation rate tensors (2)

$$[E] = \frac{1}{2}\left([S] + [S]^T\right) = \begin{vmatrix} E_{11} & E_{12} \\ E_{12} & E_{22} \end{vmatrix} \qquad [W] = \frac{1}{2}\left([S] - [S]^T\right) = \begin{vmatrix} 0 & W \\ -W & 0 \end{vmatrix}$$

[E] has 2 Eigen values : ε_1, ε_2

ε_1 and ε_2 are extension/compression along principal direction defined by angle θ (defined as angle between ε_2 direction and north)

$$\varepsilon_1 = E_{11} \cos^2\theta + E_{22} \sin^2\theta - 2 E_{12} \sin\theta \cos\theta$$

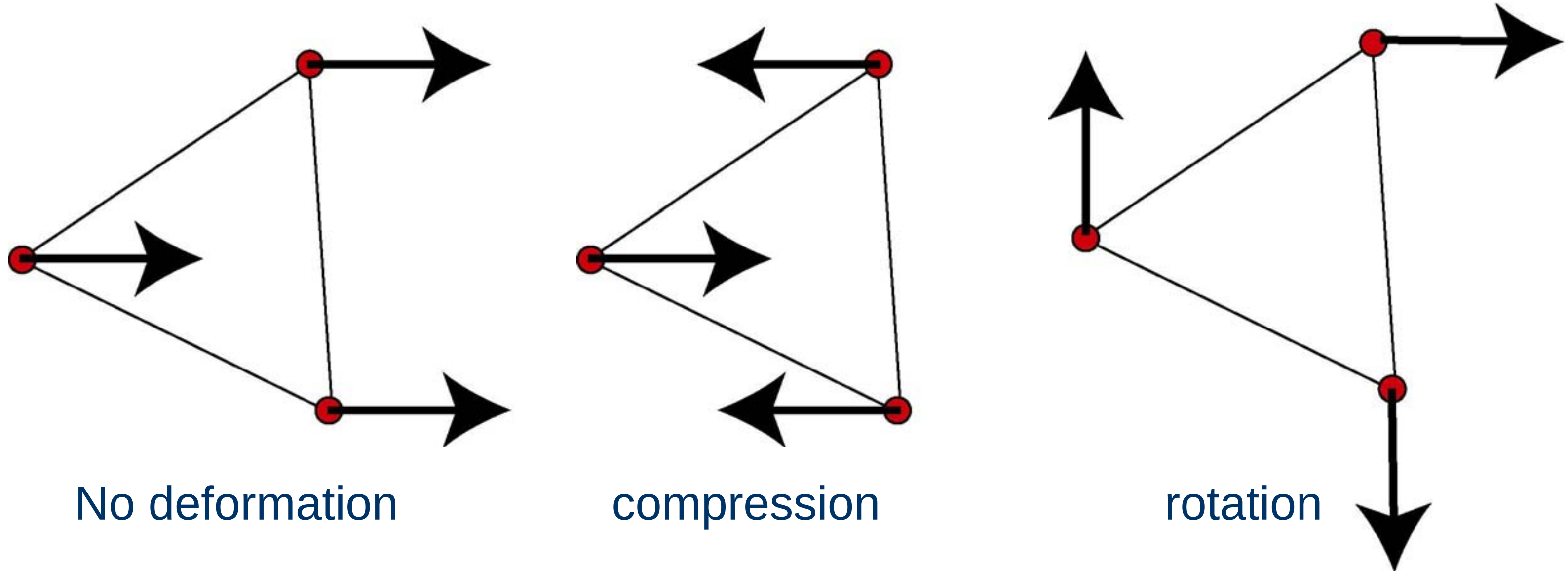
$$\varepsilon_2 = E_{11} \sin^2\theta + E_{22} \cos^2\theta - 2 E_{12} \sin\theta \cos\theta$$

Strain rate and rotation rate tensors (3)

Minimum requirement to compute strain and rotation rates is :

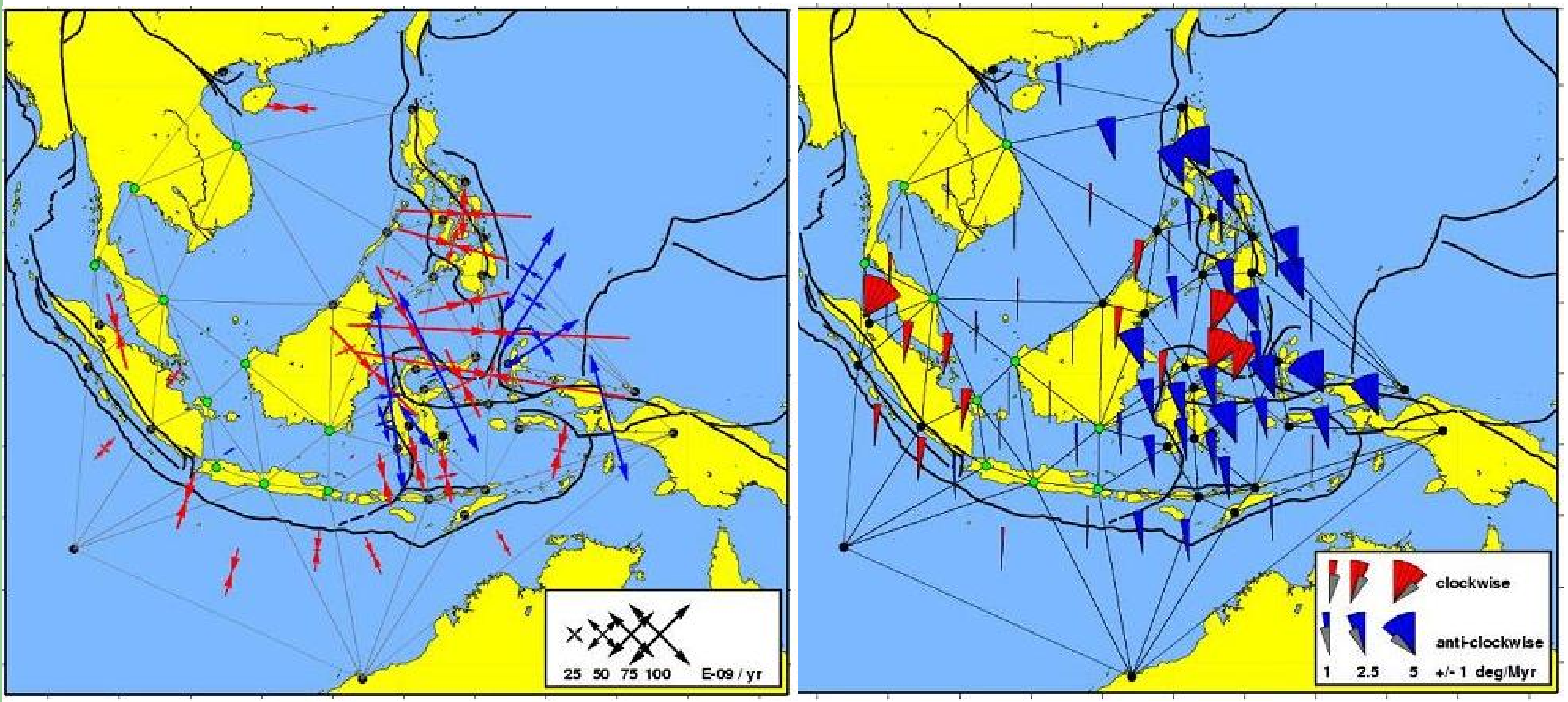
3 velocities (to allow to determine 3 values ε_1, ε_2, and W)

Therefore we can compute strain rate and rotation rate within any polygon, the minimum polygon being a triangle



Strain and rotations are unsensitive to reference frame

Strain and rotation in GEODYSSEA network



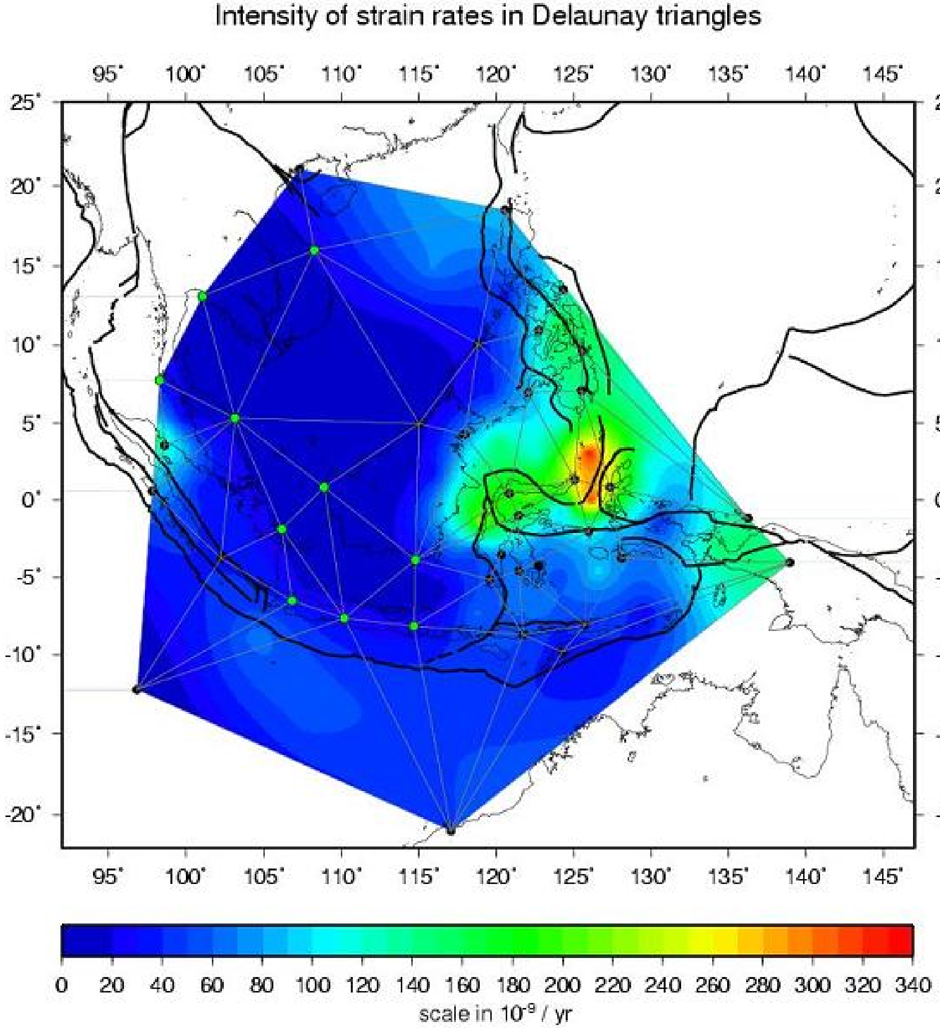
Strains :

extension/compression/strike-slip

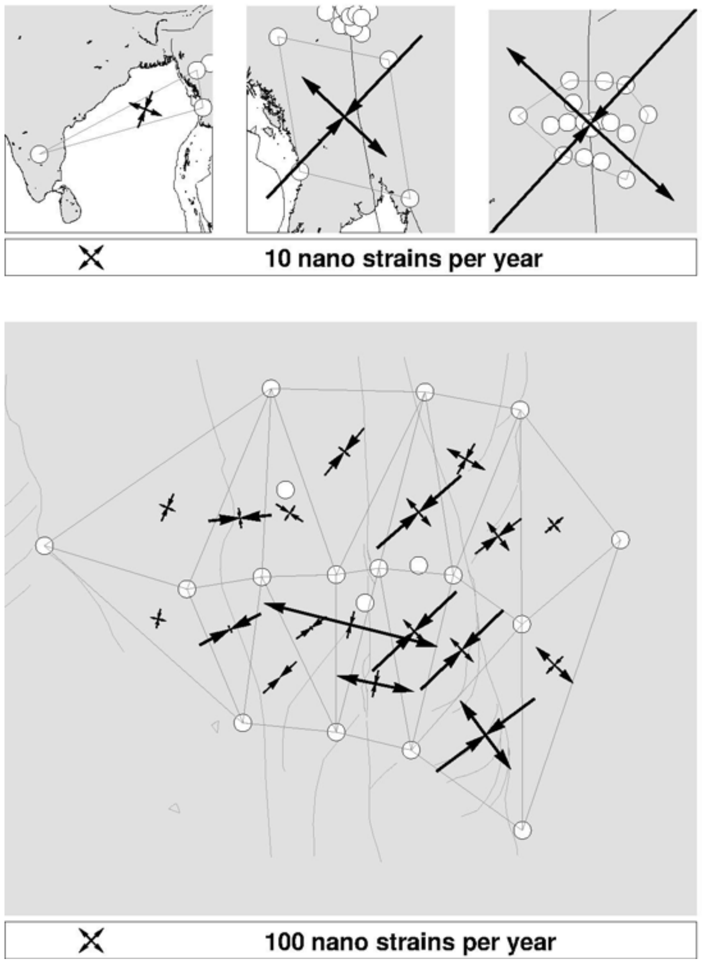
Rotations :

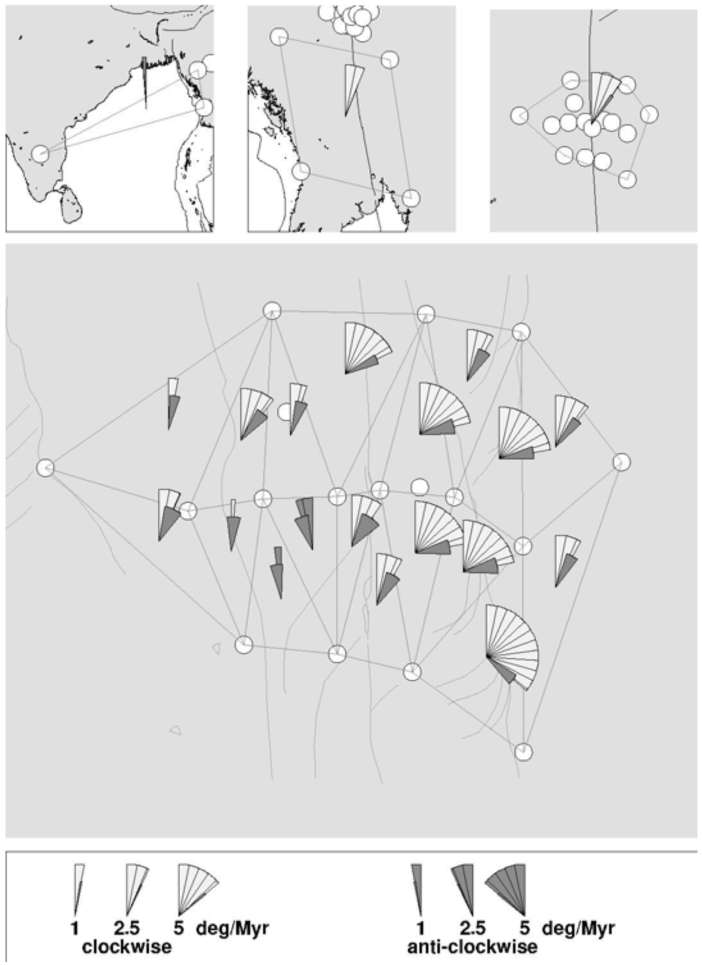
Anti-clockwise/clockwise

Intensity of strain in GEODYSSEA network

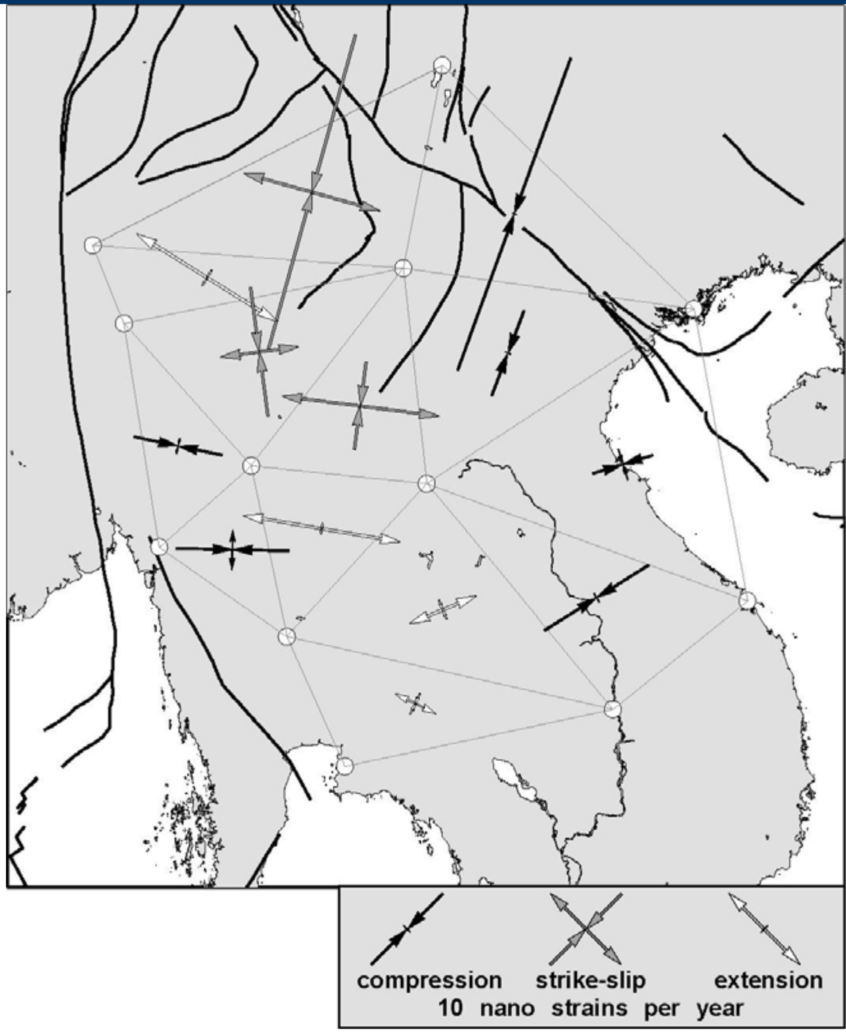


Strain and rotation in Myanmar

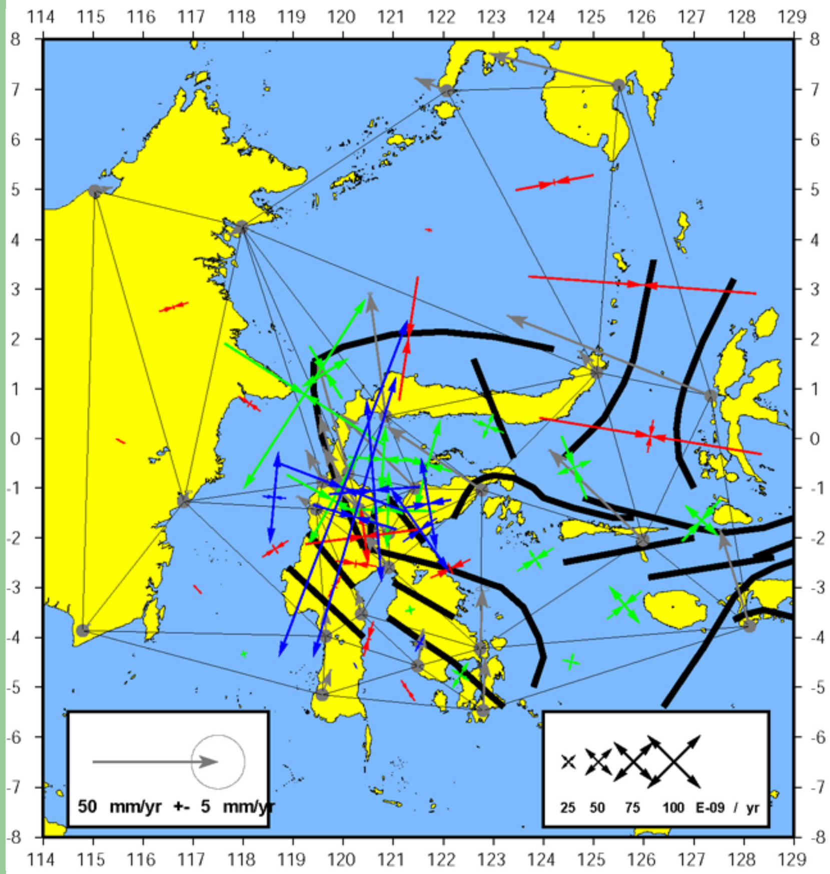


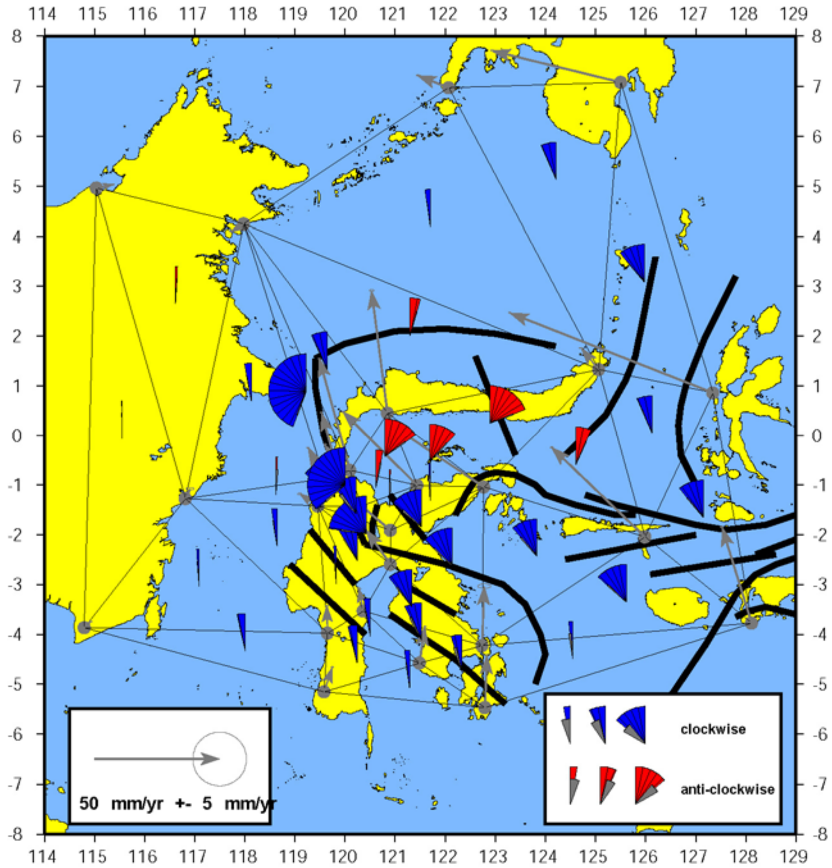


Strain in Northern Sundaland (Thailand)



Strain and rotation in Sulawesi network





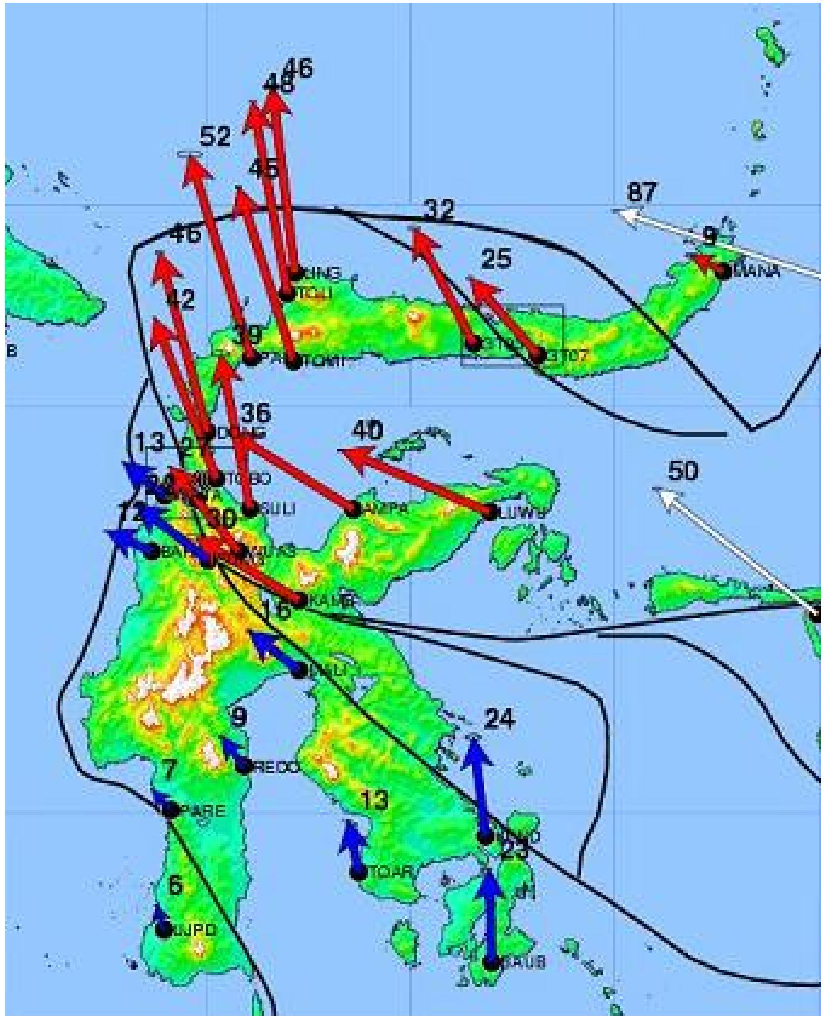
Strains :

extension/compression/strike-slip

Rotations :

Anti-clockwise/clockwise

Blocks and Internal deformation in Sulawesi



Blocks and Internal deformation in Sulawesi