Globale Seismizität II

Spannungsfeld

Seismotektonik

Literatur:

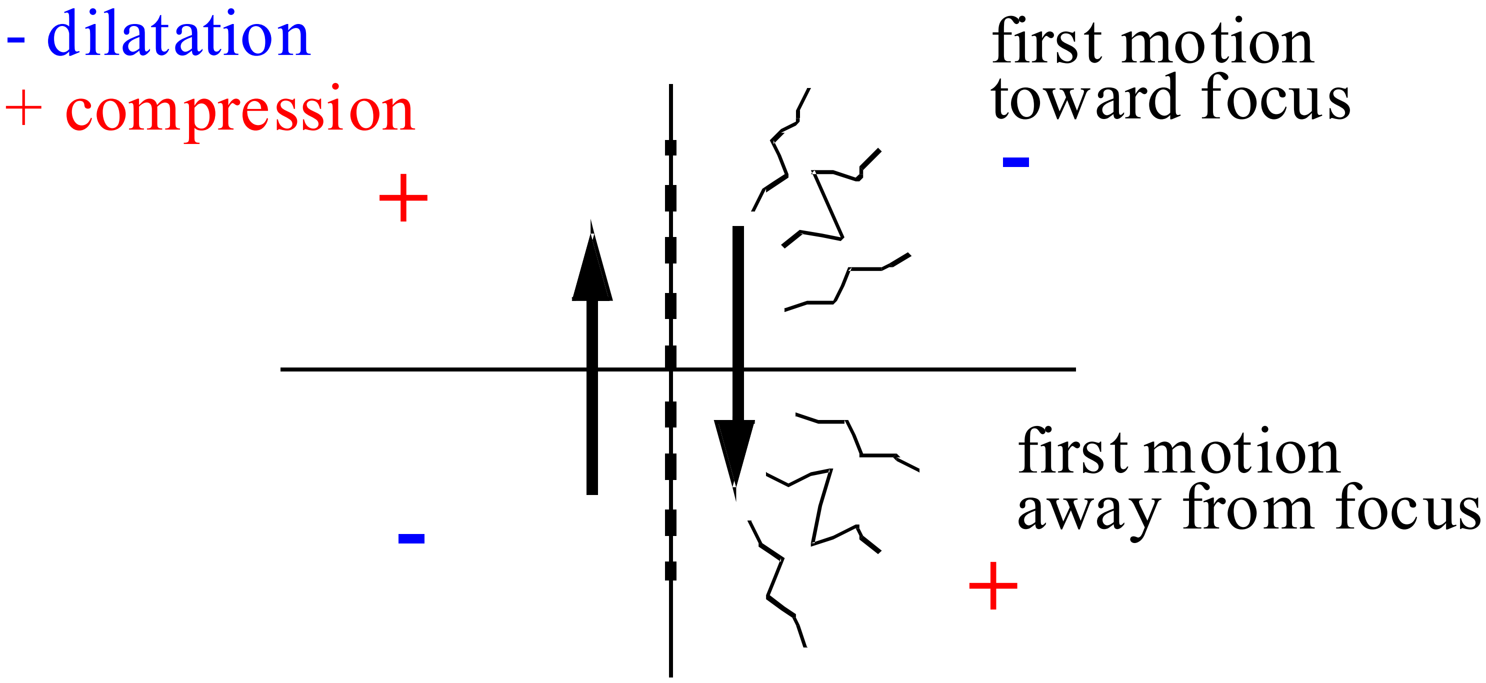
Berckhemer, H., Grundlagen der Geophysik, Wiss. Buchges. 1990.
Stüwe, K. Geodynamik der Lithospäre, Springer, 2000

Sheaer, P., Introduction to Seismology, Cambridge University Press, 1999.

Lay, T. & T. Wallace, Modern Global Seismology, Academic Press, 1995.

Wiederholung

Source deformation



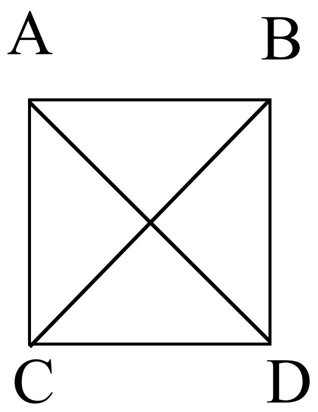
Wavetype: **P-waves (+ and - first motion)**

On nodal planes sign reversal → no displacement

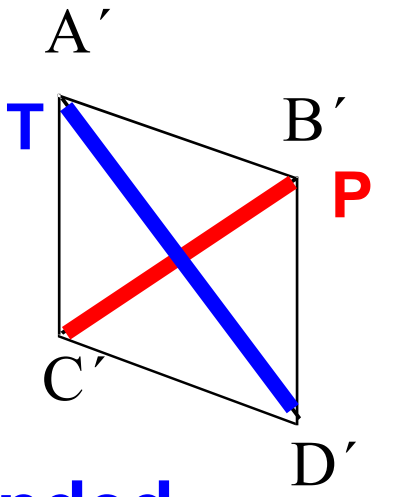
P-wave motion equal for 2 conjugate faults (fault plane and auxiliary plane)

Influence of shear on an infinitesimal volume

Volume element



Shear parallel to sides BD, AC

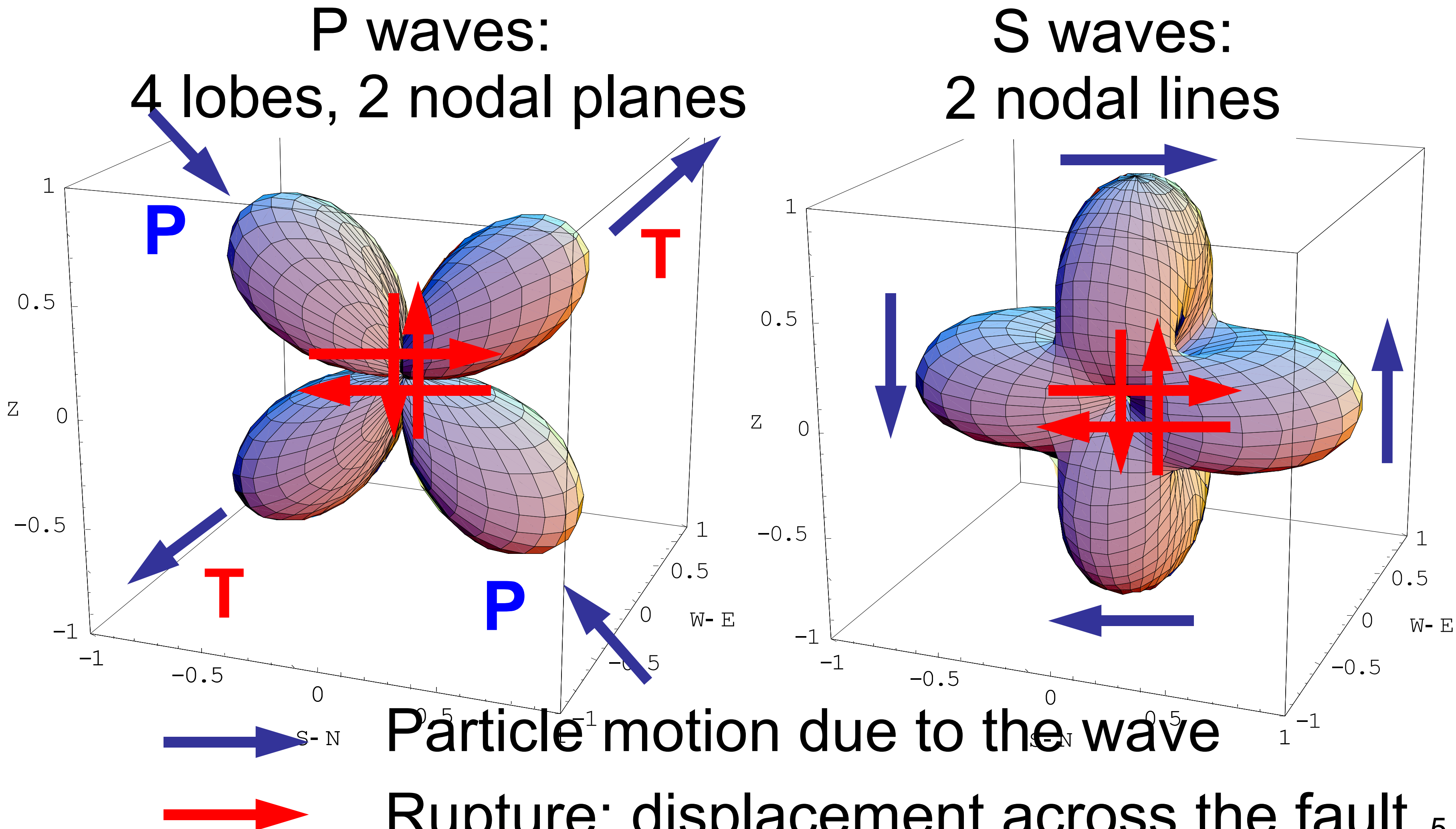


A'D' is **extended**
B'C' is **compressed**

Equal value of relative change in length but different signs

Radiation from Double couple

horizontal or vertical shear source



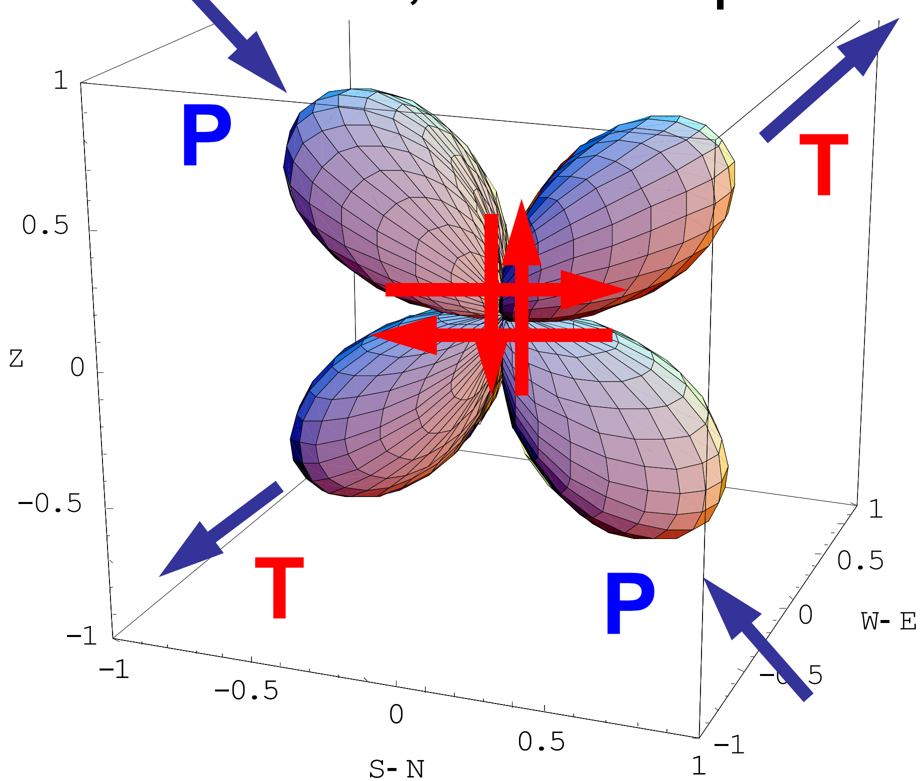
Particle motion due to the wave

Rupture: displacement across the fault

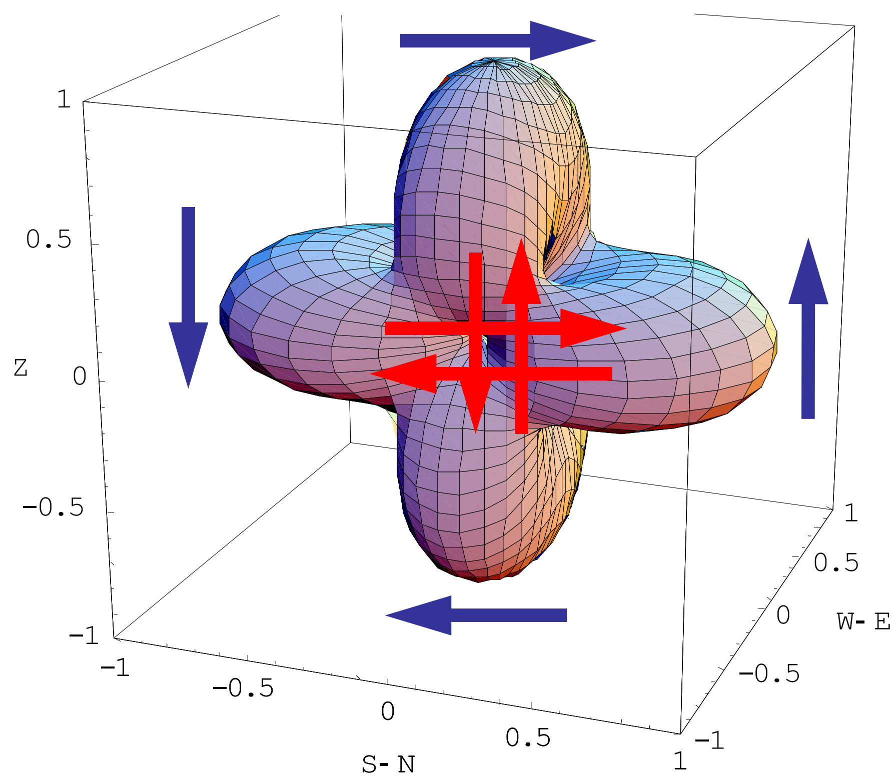
Radiation from Double couple

horizontal or vertical shear source

P waves:
4 lobes, 2 nodal planes

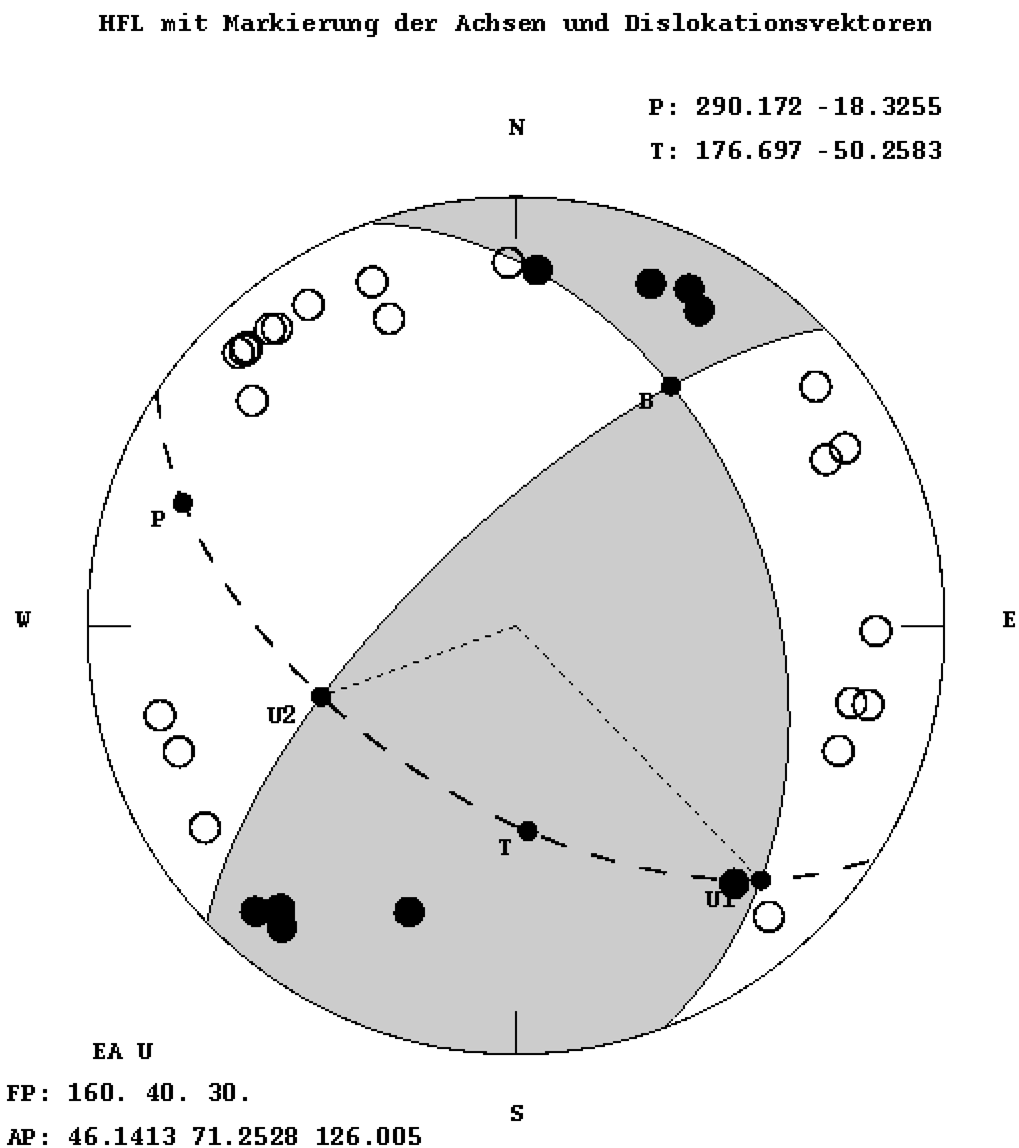


S waves:
2 nodal lines



Symmetric radiation from source: cannot distuingish fault plane and auxiliary plane

Fault-Plane solutions



P- and T-axes

= directions of maximal compression/extension in radiation pattern

Generally P, T **NOT** equal tectonic stress axes, only under 45° - hypothesis

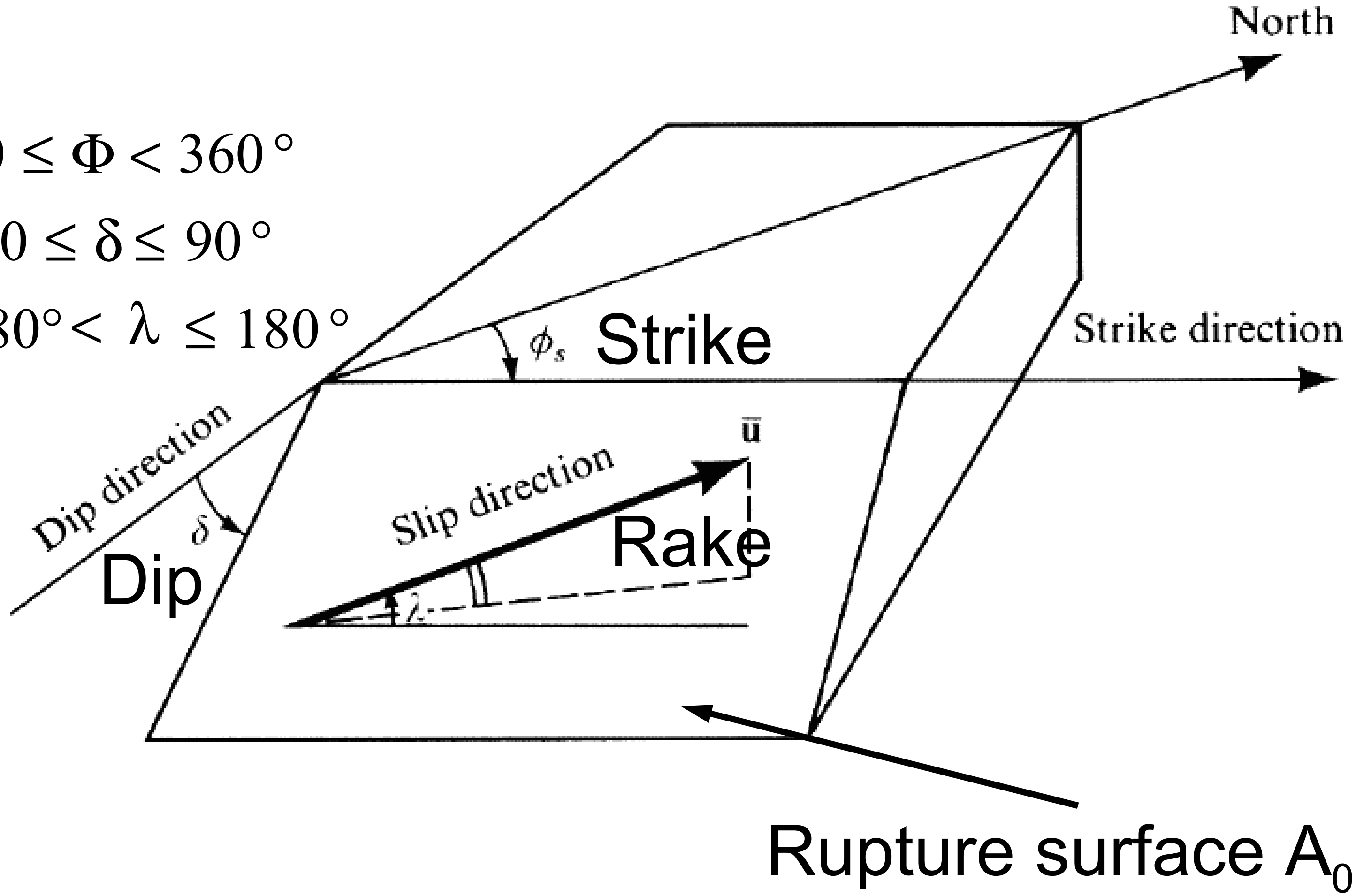
e.g. San-Andreas fault: max. principal stress ⊥ fault

Point source - shear dislocation Definition of strike, dip, slip (Streichen, Fallen, Neigung)

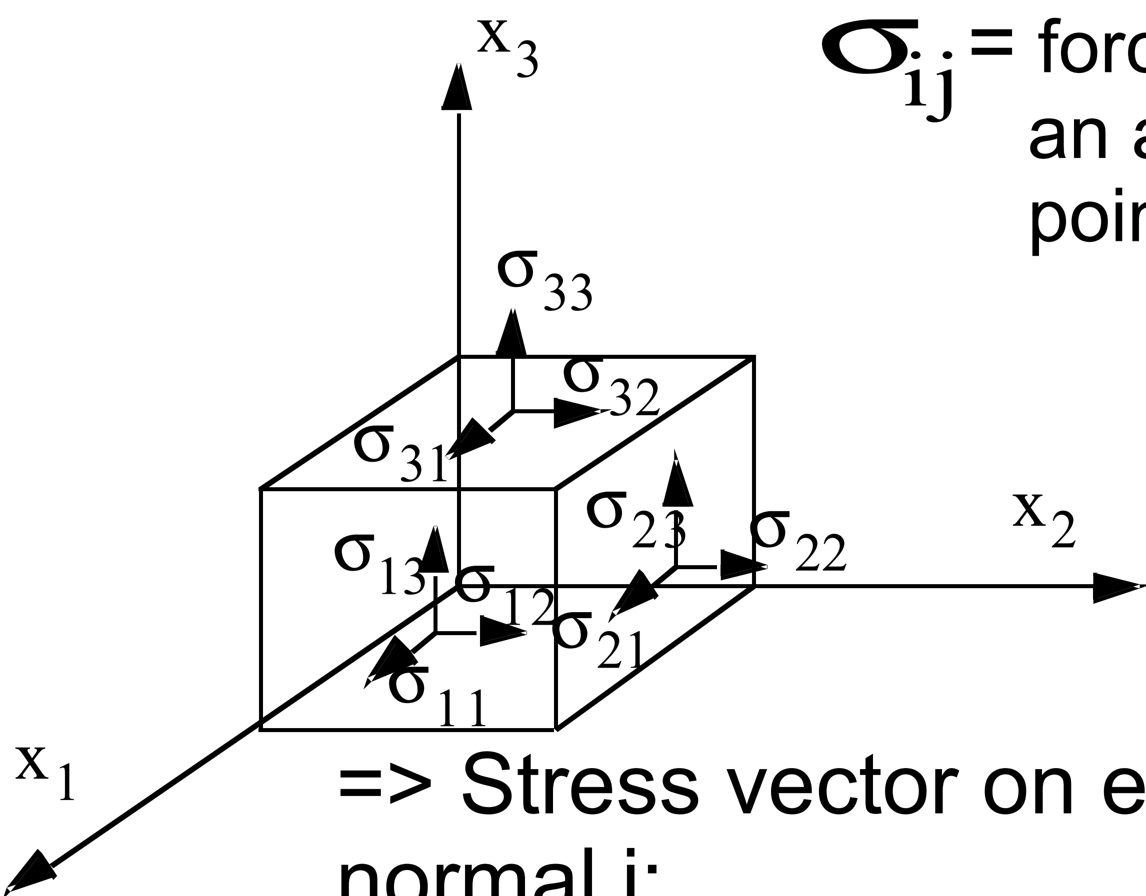
$$0 \le \Phi < 360°$$

$$0 \le \delta \le 90°$$

$$-180° < \lambda \le 180°$$



Meaning of σ_{ij}:

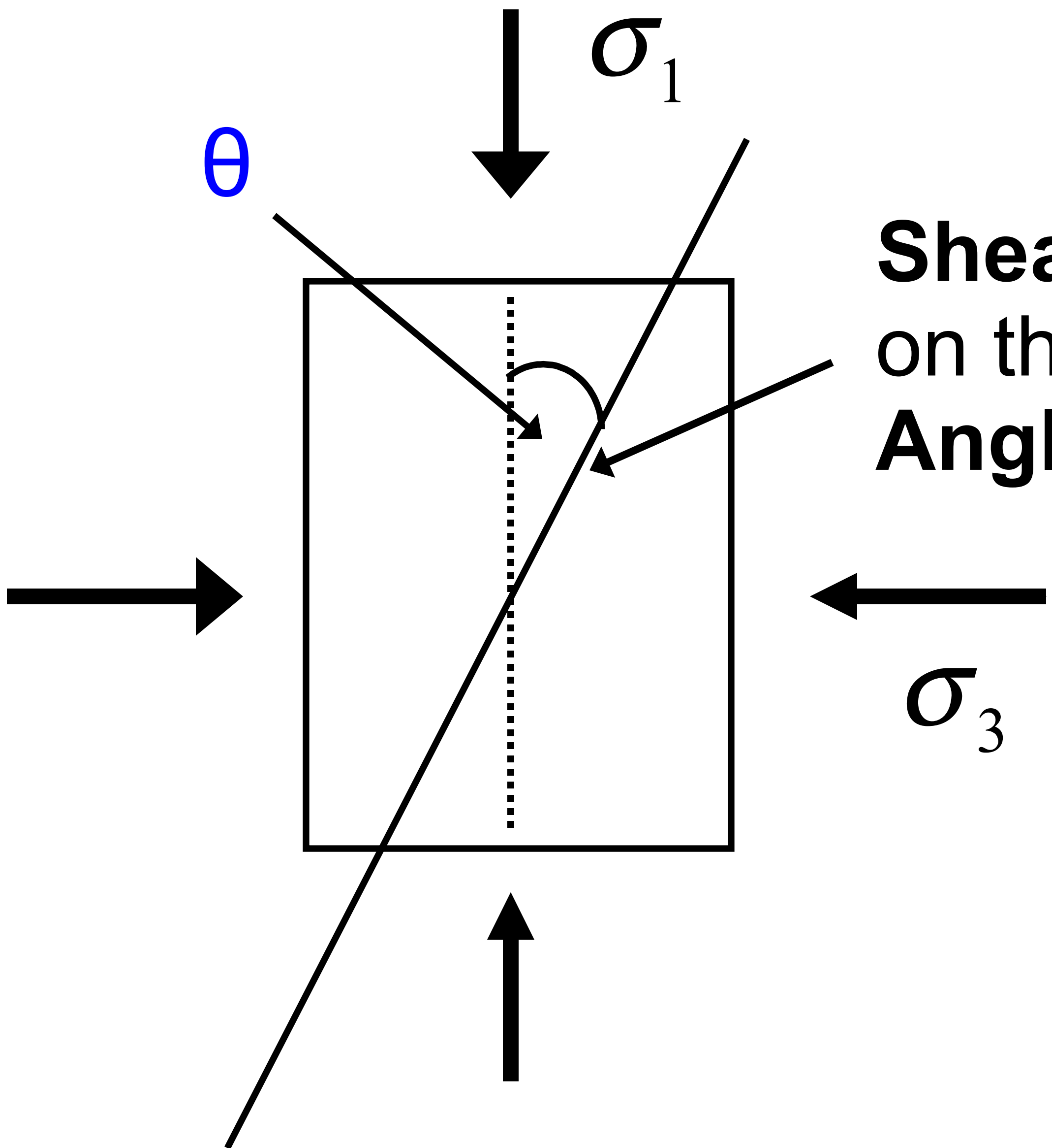


σ_{ij} = force in j direction on an area whose normal points to i direction

=> Stress vector on each area with normal i:

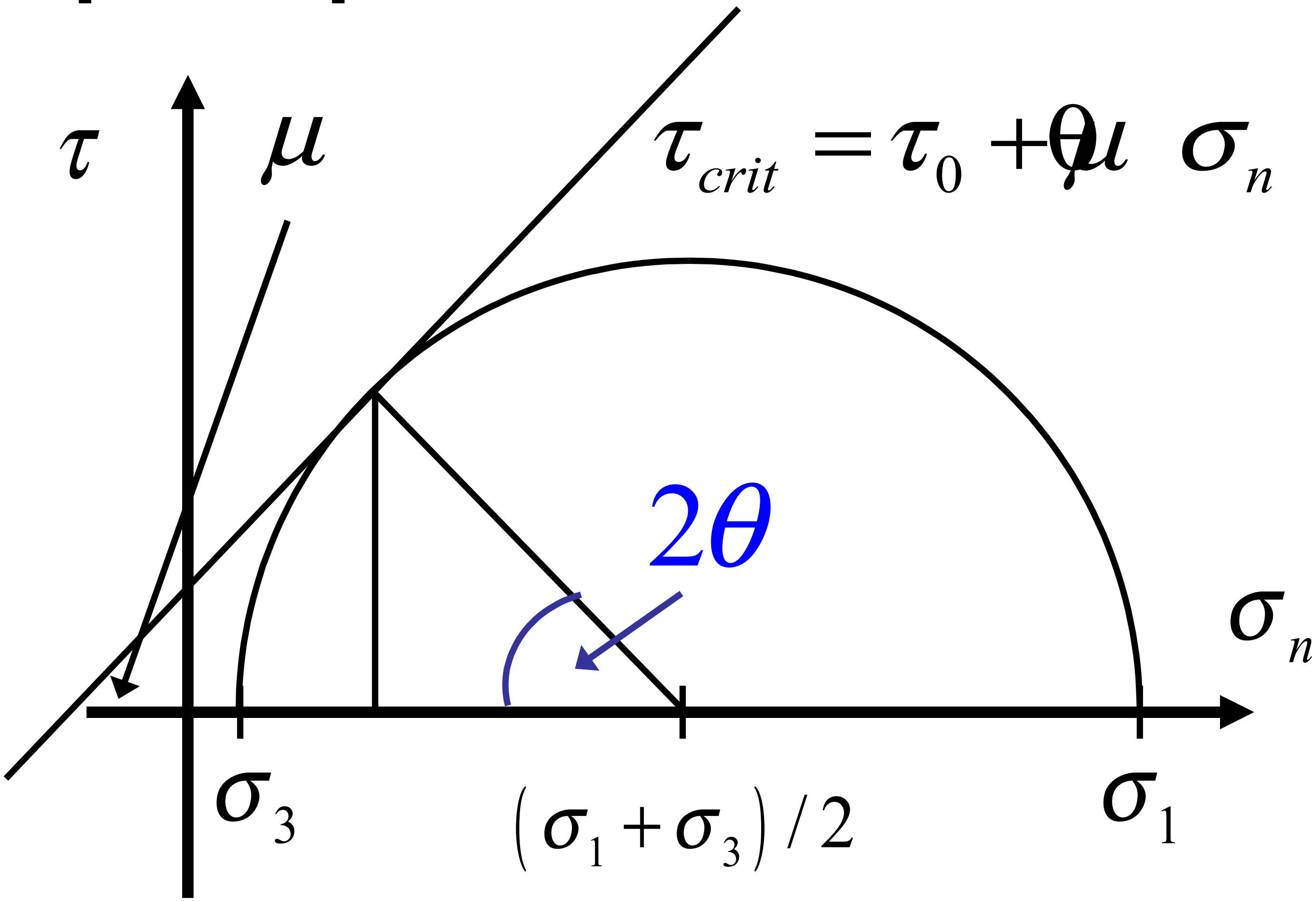
$$\vec{T}^{(i)} = (T_1^{(i)}, T_2^{(i)}, T_3^{(i)}) = (\sigma_{i1}, \sigma_{i2}, \sigma_{i3})$$

Shear stress τ on arbitray plane?



Shear Stress τ
on this plane?
Angle θ of rupture?

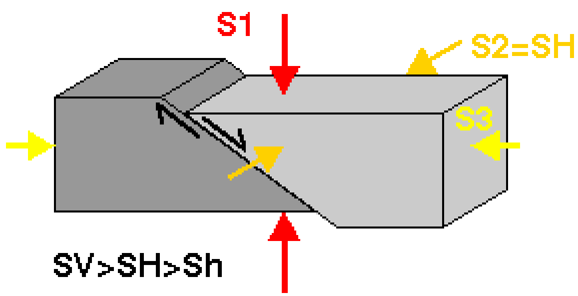
Rupture plane and Mohr circle



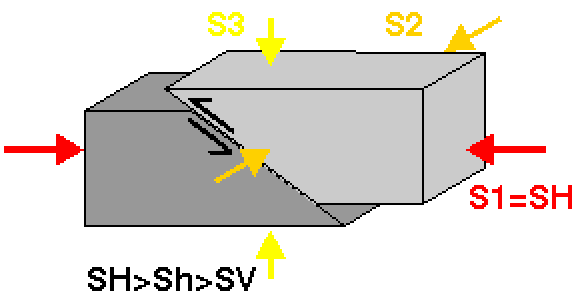
Real materials do **not** rupture under 45° to σ_1!

θ depends on μ, normally θ≈30°

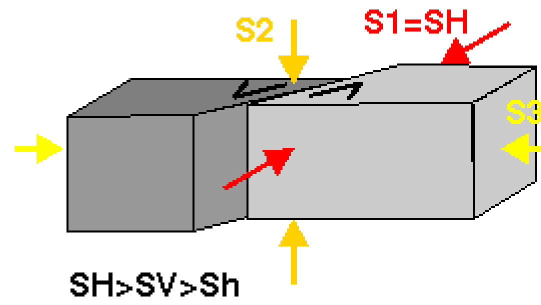
Fault types & stress regimes



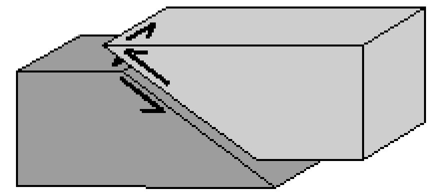
NF: Normal faulting

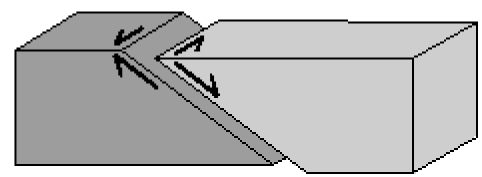


TF: Thrust faulting



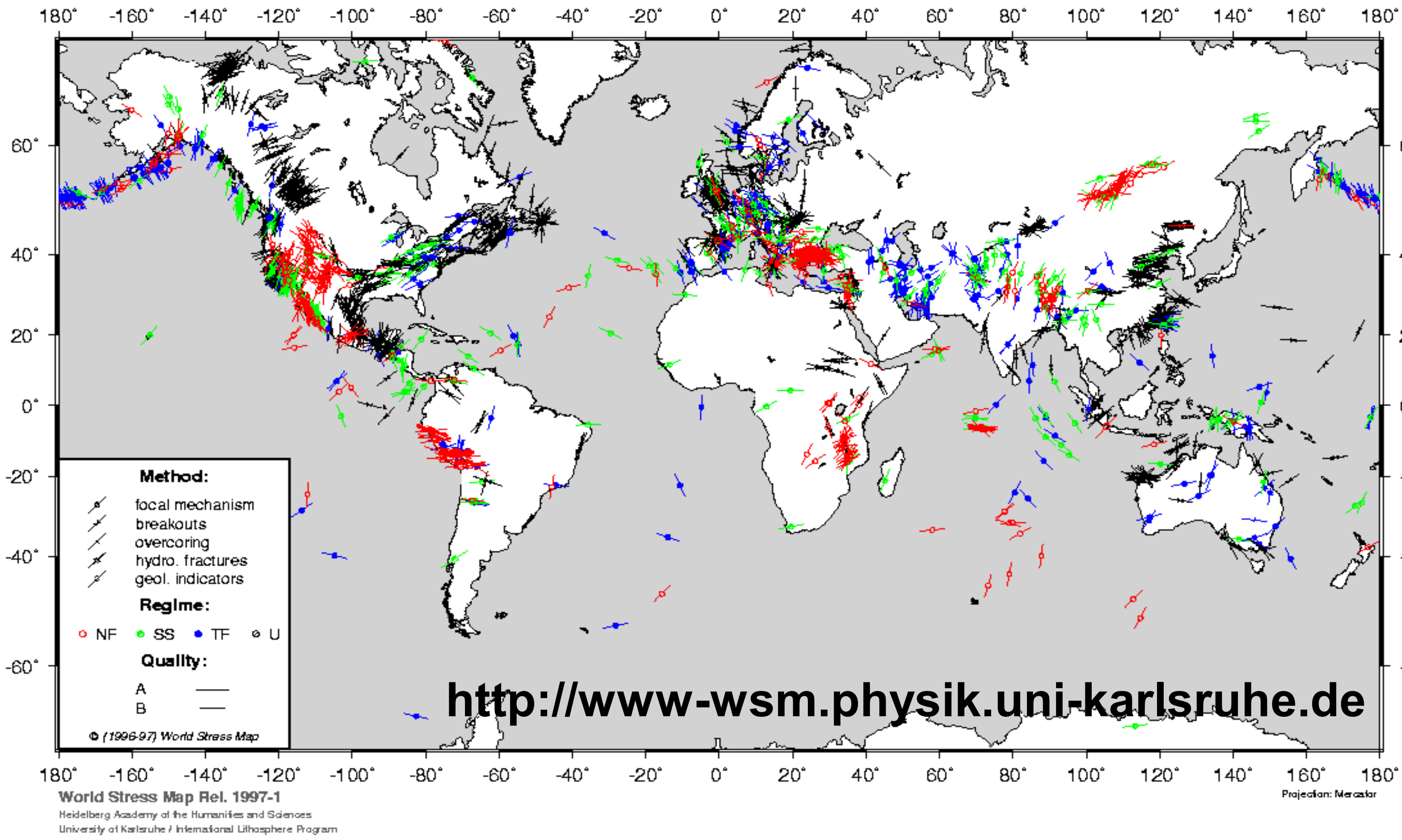
SS: Strike-slip faulting (includes minor normal or thrust component)


TS: Predominately thrust with strike-slip component


NS: Predominately normal with strike-slip component

If Coulomb criterium applies: first estimate stress field from fault-plane solution dependent on coefficient of internal friction.

B World Stress Map Projekt



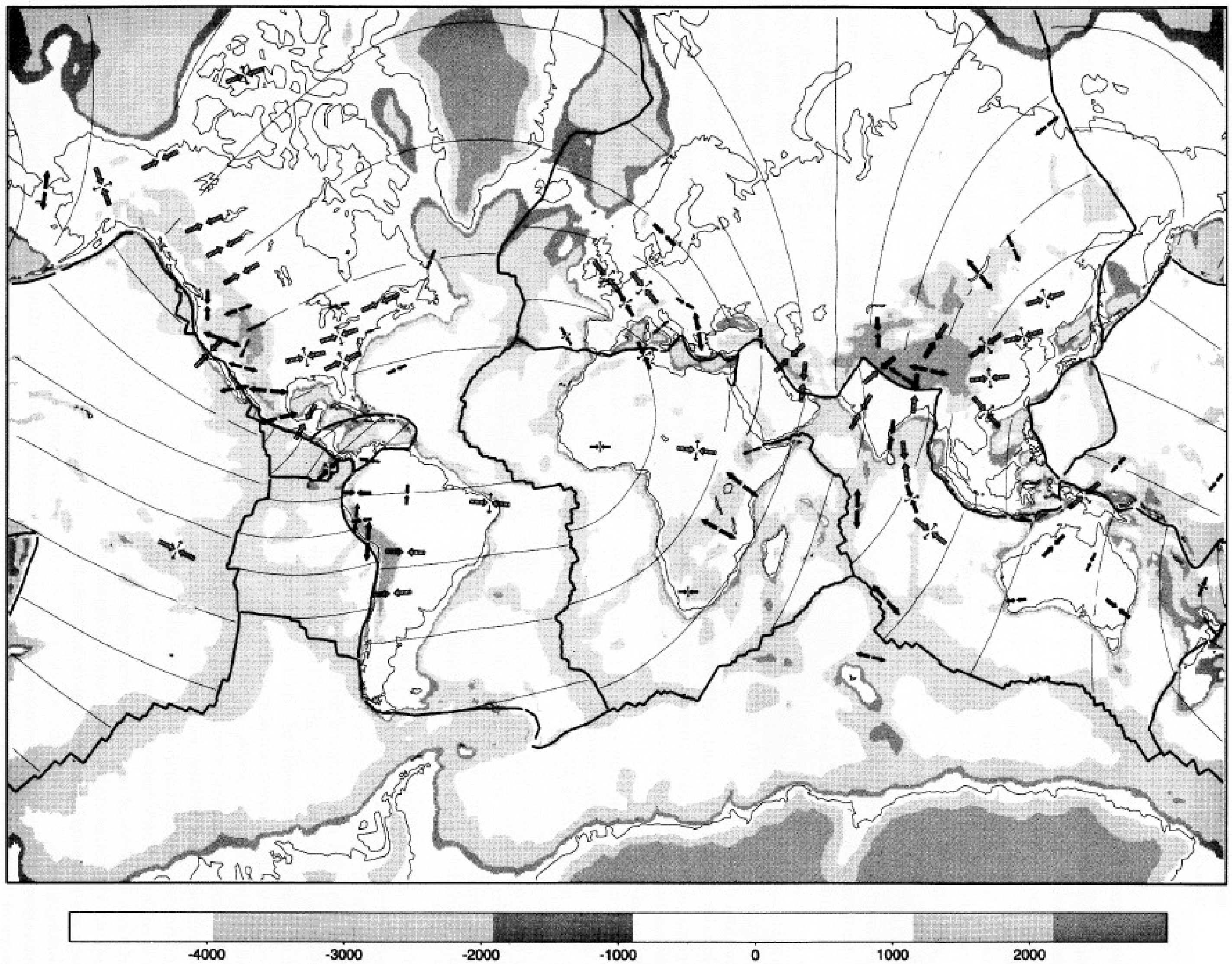
Compilation of the global stress field, S_{Hmax} directions

30 groups, > 18 countries, 54% FPS, 28% borehole, breakouts, 4.5% hydrofracs, 3.4% overcoring, 4.1% volcano alignment

Global results, first order effects

- In brittle crust almost everywhere consistent stress field
- Intraplate areas: horizontal σ_1 => strike slip, thrust
- Extension often in areas of high topography
- Stress provinces with consistent σ_1, σ_3

Generalized stress map



thrust

normal fault

strike slip

Forces acting on a plate

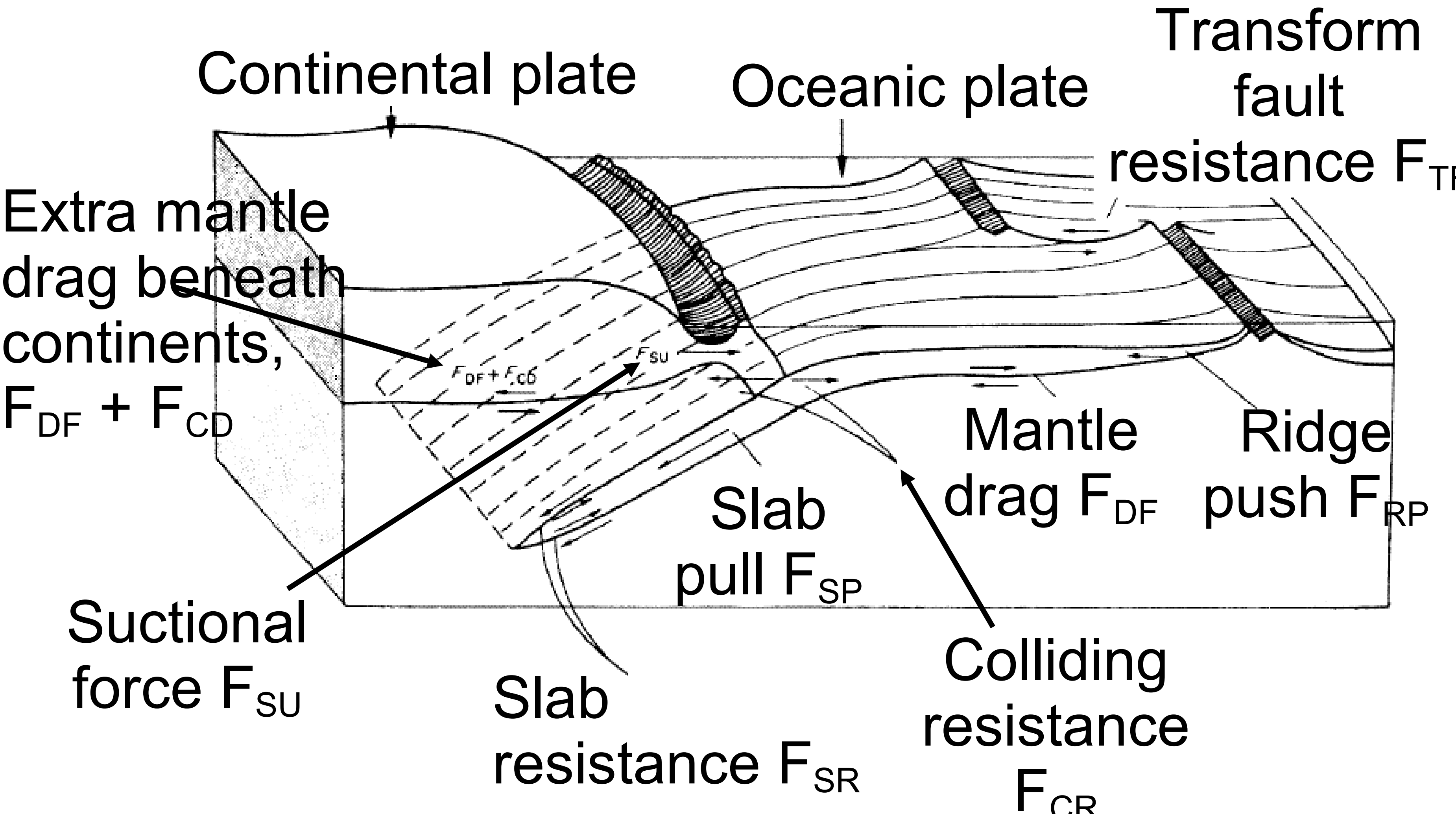


Bild: Fowler S. 368 (Fig. 8.20)

First order global stress patterns

TABLE 4. First-Order Global Stress Patterns

Region	S_{Hmax} or S_{hmin} Orientation[a]	Stress Regime[b]	Primary Source of Stress and Comments	References: State of Stress	References: Stress Modeling
			North American Plate		
Midplate region	ENE	T/SS	primarily ridge push, lateral stress variations predicted for basal drag not observed, regionally extensive (~2 × 10^7 km^2)	*Adams and Bell* [1991] and *Zoback and Zoback* [1989, 1991]	*Richardson and Reding* [1991]
Western Cordillera, Central America, and Alaska			complex stress patterns beyond scope of discussion, largely related to superposition of buoyancy forces and distributed shear related to Pacific–North American relative motion	many references, see summaries by *Zoback and Zoback* [1989, 1991], *Suter* [1991], *Suter et al.* [this issue], and *Estabrook and Jacob* [1991]	
			South American Plate		
Continental	E	T/SS	primarily ridge push, torque analysis suggests driving drag possibly major force [*Meijer and Wortel*, this issue]	*Assumpcao* [this issue]	*Stefanick and Jurdy* [this issue] and *Meijer and Wortel* [this issue]
High Andes	N	NF	trench suction or buoyancy due to thick crust and/or thinned lithosphere	*Froidevaux and Isacks* [1984] and *Mercier et al.* [this issue]	*Whittaker et al.* [this issue] and *Stefanick and Jurdy [this issue]*
			Eurasian Plate		
Western Europe	NW	SS	combined effects of ridge push and continental collision with Africa dominate, absolute velocity ≈ 0; thus resistive or driving basal drag probably not important; lateral variations in lithospheric structure may locally influence stress field	*Klein and Barr* [1987], *Gregersen* [this issue], *Grünthal and Stromeyer* [this issue], and *Müller et al.* [this issue], and Rebai et al. [1992]	*Brudy* [1990] and *Günthal and Stromeyer* [this issue]
China/eastern Asia	N to E	SS	continental collision force domimates, indentor geometry extremely important	*Molnar and Tapponnier* [1975], *Molnar and Deng* [1984], and *Xu et al.* [this issue]	*England and Houseman* [1989], *Tapponnier and Molnar* [1976], and *Vilotte et al.* [1984, 1986]
Tibetan Plateau	WNW	NF	Buoyancy (due to thick crust and/or thinned upper mantle) overcomes compression due to continental collision force	*Molnar and Tapponnier* [1978], *Mercier et al.* [1987*b*], and *Burchfiel and Royden* [1985]	*England and Houseman* [1989] and *Vilotte et al.* [1986]
			African Plate		
East African rift	NW	NF	Buoyancy force overcomes ridge push compression	*Bosworth et al.* [this issue]	
Midplate (western and southern Africa)	E	SS	ridge push dominates absolute velocity ≈ 0; thus drag probably not important	this paper, using data of *Bosworth et al.* [this issue], *Suleiman et al.* [1989], and D. I. Doser (written communication, 1990)	
North Africa	N to NW	T/SS	continental collision with Europe dominates	*Rebai et al.* [1991] and *Kamoun and Hfaiedh* [1985]	
			Indian Australian Plate		
India	N to NE	T/SS	continental collsion	*Gowd et al.* [this issue]	*Cloetingh and Wortel* [1985, 1986]
Central Indian Ocean	N to NW	T/SS	complex interaction collision and trench forces, long-wavelength basement undulations due to stress-induced flexure?	*Bergman* [1986], *C. Stein et al.* [1989], and *Petroy and Wiens* [1989]	*Cloetingh and Wortel* [1985, 1986] and *Gover et al.* [this issue]

First order global stress patterns (2)

TABLE 4. (continued)

Region	S_{Hmax} or S_{hmin} Orientation[a]	Stress Regime[b]	Primary Source of Stress and Comments	References: State of Stress	References: Stress Modeling
			Indian Australian Plate (continued)		
West Indian Ocean	N to NW	NF	high level of intraplate seismicity with S_{hmin} parallel to nearby mid-ocean ridges, due to thermoelastic stresses or comple geometry of plate-driving forces?	*Bergman et al.* [1984], *Wiens and Stein* [1984], and *Stein et al.* [1987]	*Cloetingh and Wortel* [1985,1986], *Bratt et al.* [1985], and *Gover et al.* [this issue]
Central Australia and northwest shelf	N to NE	TF	much scatter in stress orientations; however, best data suggest consistent north to NNE S_{Hmax} directions	this paper	*Cloetingh and Wortel* [1985, 1986]
Southern coastal Australia	E	TF	source of E-W stress unknown		
			Pacific Plate		
Young (<70) crust	NE	SS	ridge push, slab pull, drag all give same orientation	*Okal et al.* [1980] and *Wiens and Stein* [1984]	*Richardson et al.* [1979], *Bai et al.* [this issue], *Wortel et al.* [1991], and *Gover et al.*, [this issue]
Older crust (>70)	NW?	T/SS	driving drag would predict extension, not observed compression; extension predicted due to mantle upwelling central Pacific also not observed	*Wiens and Stein* [1985] and *Zoback et al.* [1989]	*Richardson et al.* [1979], *Bai et al.* [this issue], *Wortel et al.* [1991], and *Gover et al.* [this issue]
			Nazca Plate		
Midplate	?	?	only one earthquake focal mechanism available		*Wortel and Cloetingh* [1985] and *Richardson and Cox* [1984]
			Antarctic Plate		
Midplate	?	?	expected stress state is radial compression (surrounded by ridges), one focal mechanism available, seismicity suppressed by ice sheet?	*Johnston* [1987]	
West Antarctic rift	E to NE	NF	Cenozoic rift system with basalts as young as Holocene; buoyancy forces dominate midplate compression	*Behrendt et al.* [1991] and *Behrendt and Cooper* [1991]	

[a] S_{Hmax} orientation given for thrust or strike-slip faulting stress regimes; S_{hmin} given for normal faulting stress regimes.
[b] NF, normal faulting stress regime; SS, strike-slip faulting stress regime; TF, thrust fauting stress regime; T/SS, combined thrust and strike-slip regimes (see text for definitions of stress regimes).

Interpretation of first order stress patterns

1. Compression within plates due to compressive forces acting on plate margins (ridge push, continental collision)

2. Buoyancy in regions of high elevation (Tibet) can locally compensate intra plate compression

3. Basal drag difficult to estimate

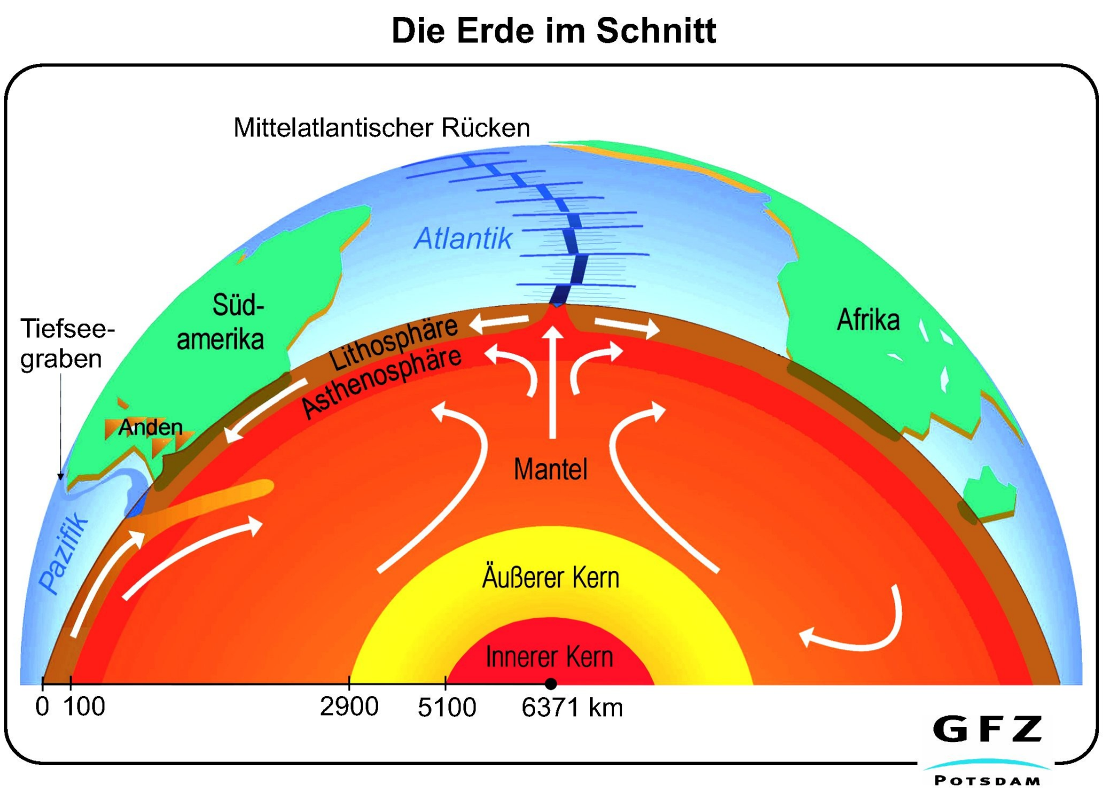
Higher order stress patterns

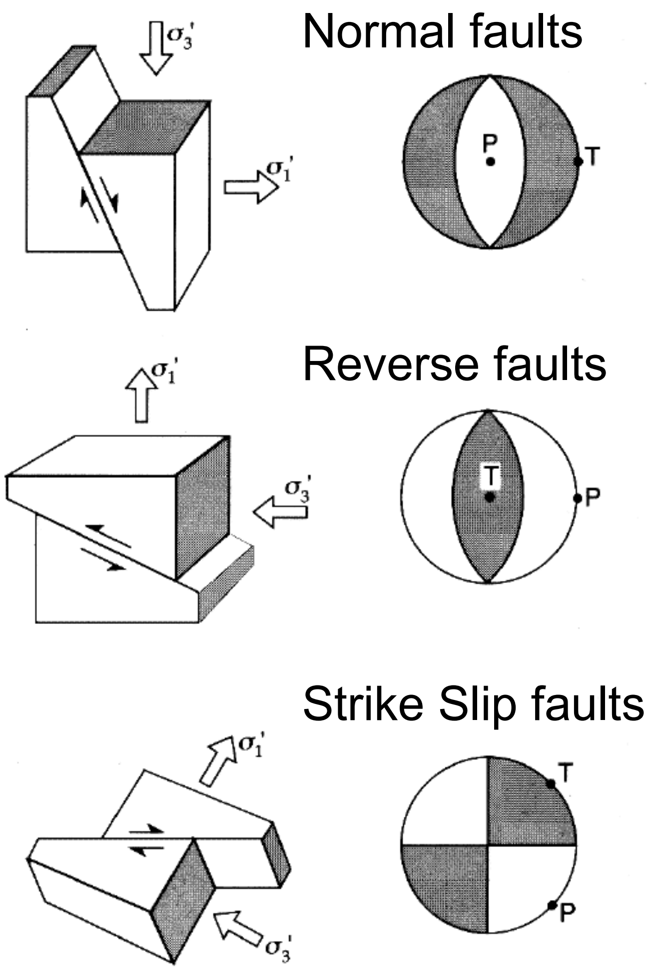
Variety of effects:

- Deflection due to load (ice, sediments, sea mounts), at subduction zones (outer arc bulge)
- Lateral density contrasts (intrusions, isostatically uncompensated orogens)
- Lithosphere thinning (East African Rift) => intra plate extension
- Lithosphere thickening (Colorado Plateau, Western Alps) => rotation of σ_1

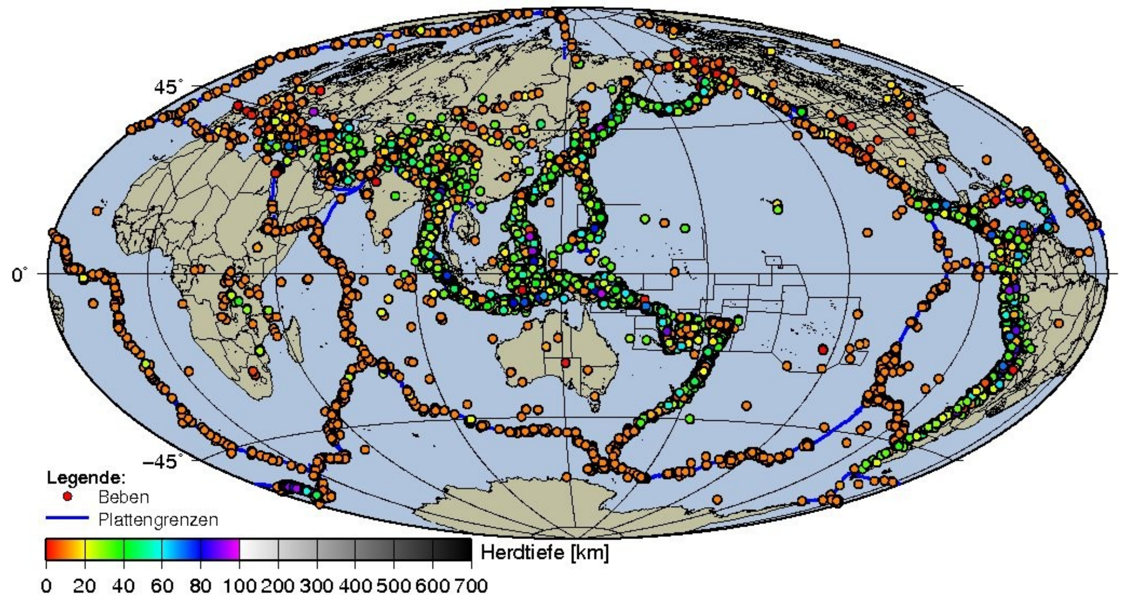
Tectonics at active plate margins:

3 types: constructive, destructive, conservative

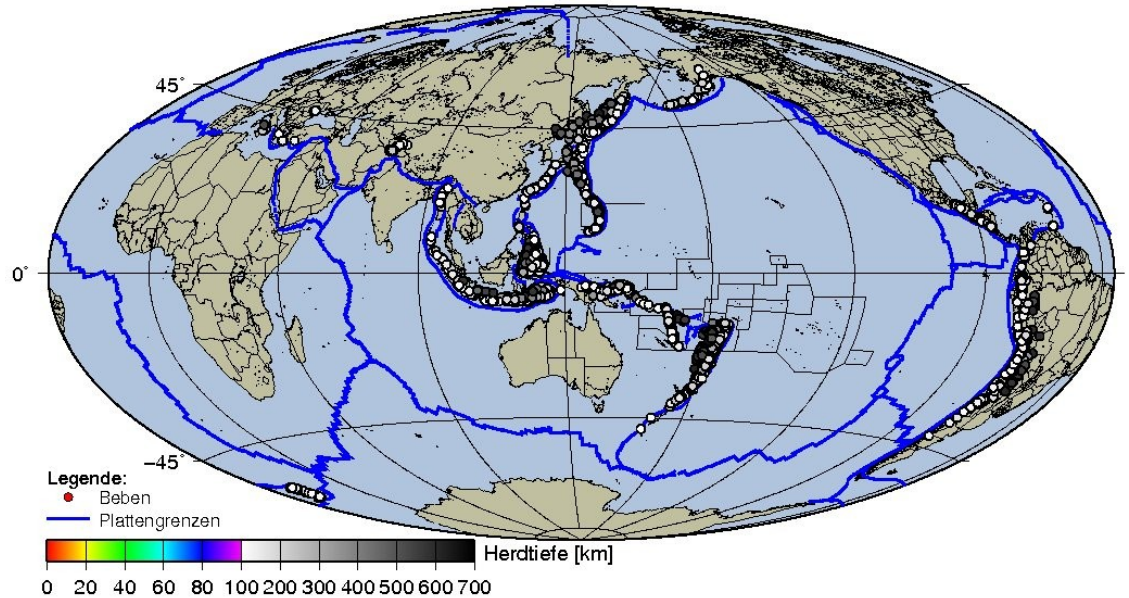




Global earthquake distribution 1995 – 2006



Source depth < 100 km



Source depth from 100 to 700 km

Active plate margins:

I. Spreading centers:

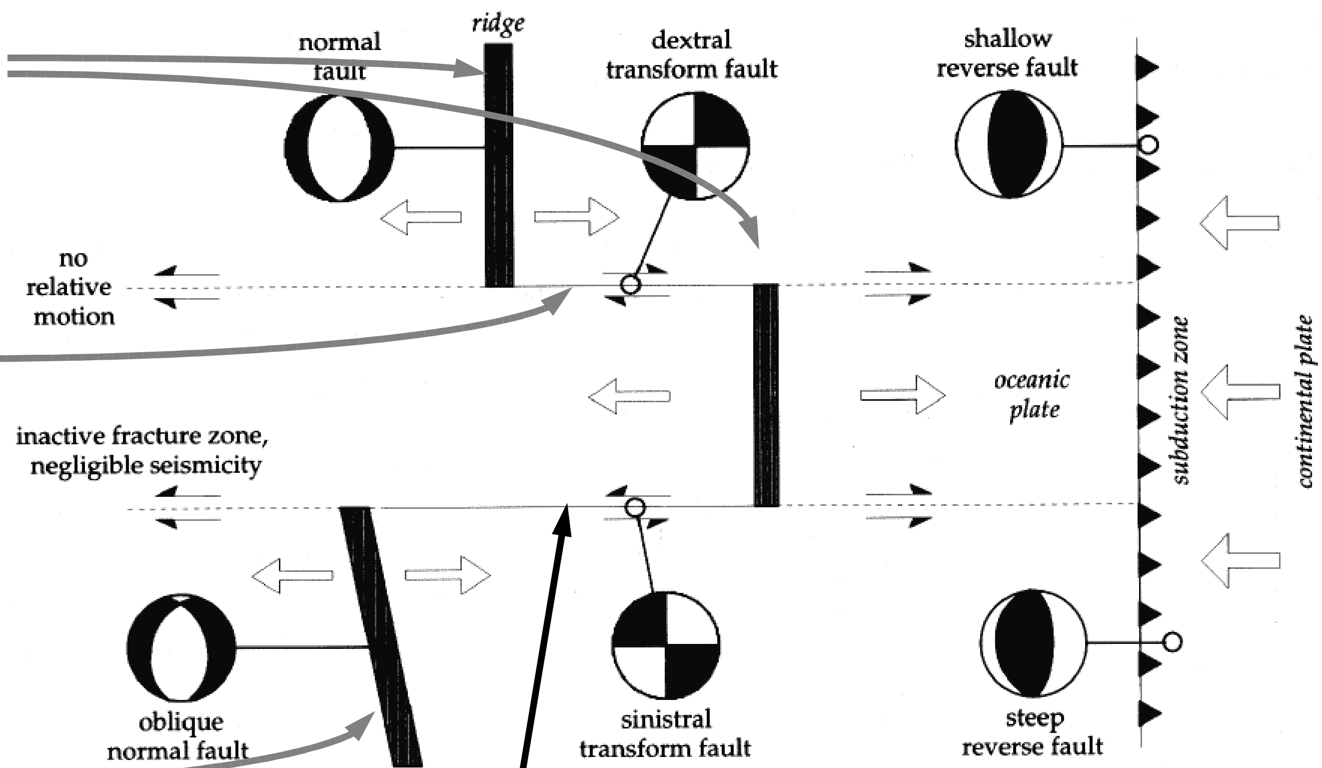
- Constructive & conservative faults
- Seismicity bound to narrow, flat (< 10 km) regions
- Active ridges: new oceanic crust generated, consequence: extension

Fault plane solutions at an ocean ridge – transform fault system

Apparent sinistral offset of ridge

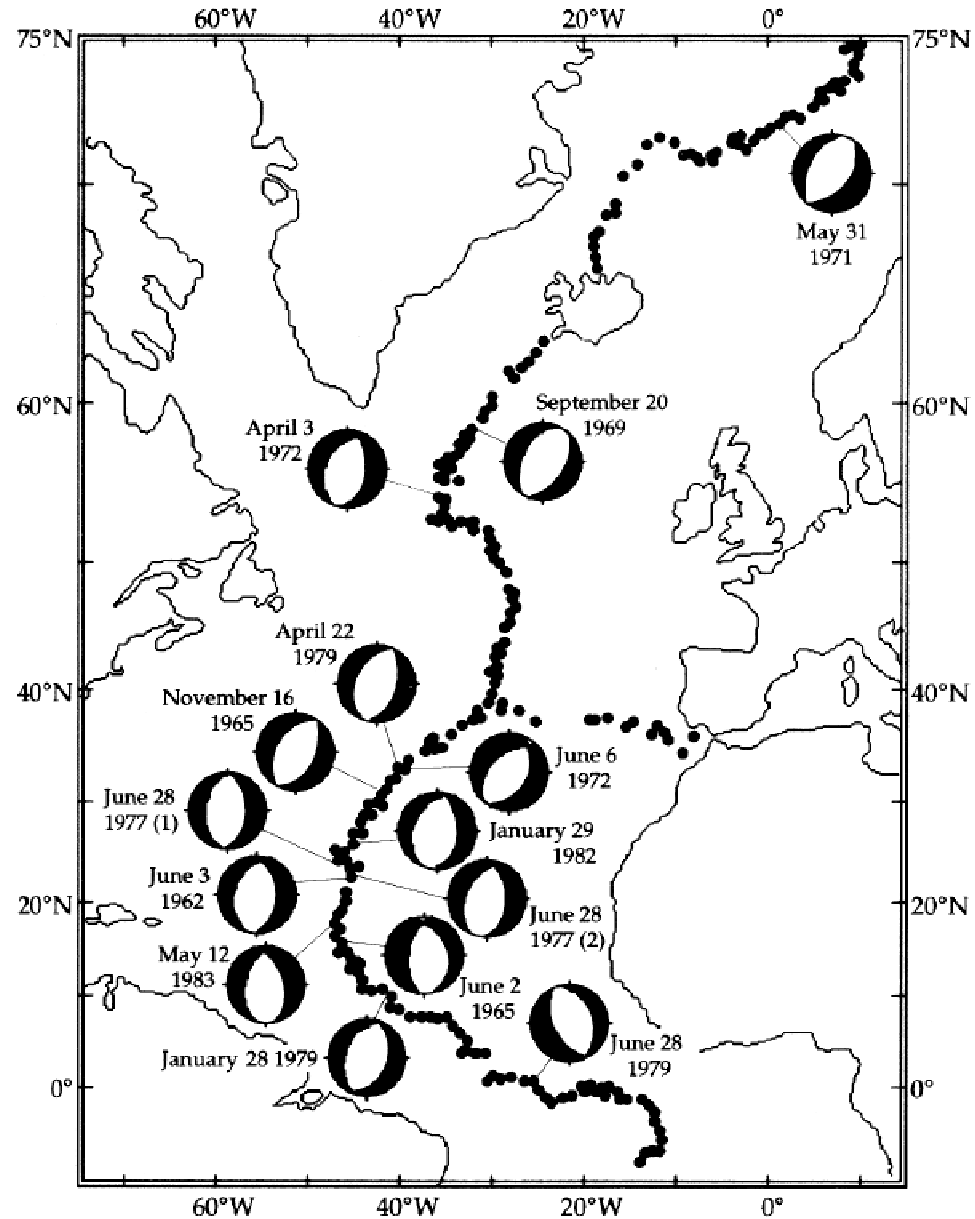
Dextral sense of motion at transform fault

Drift **oblique** to ridge

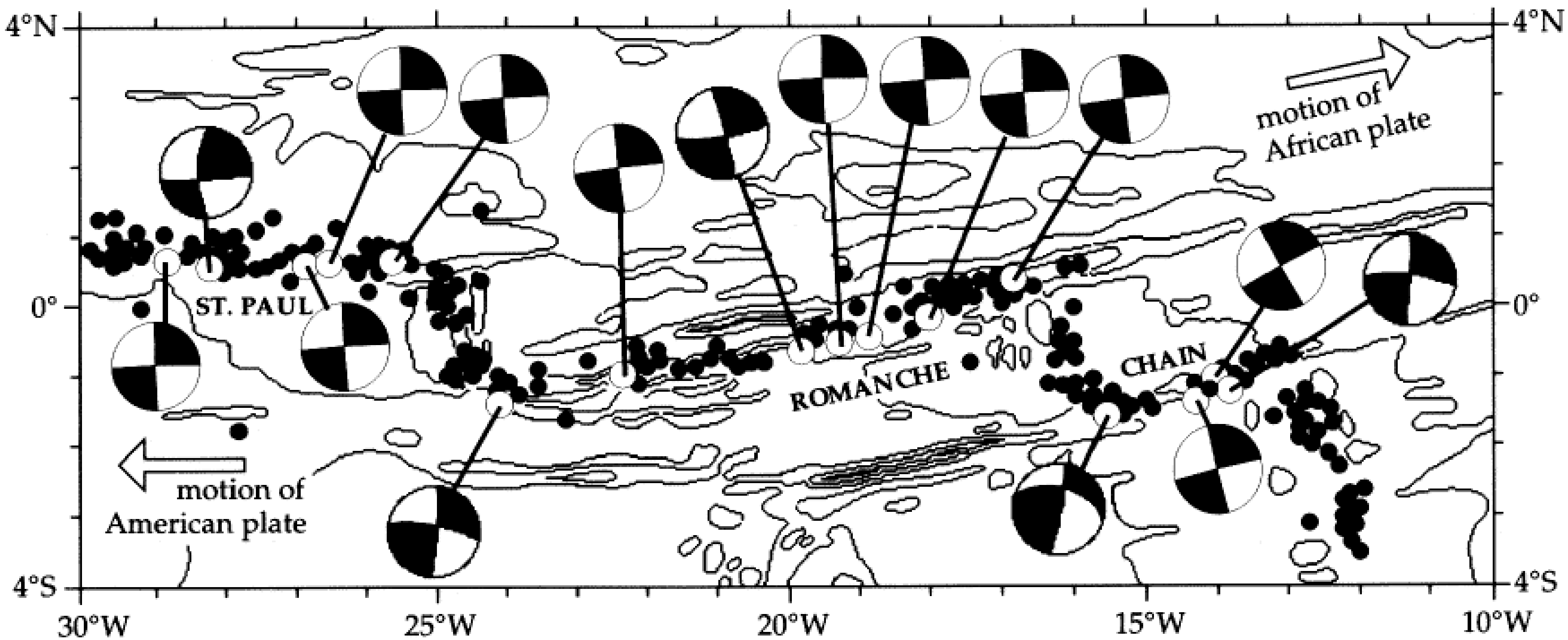


MOR segments connected by transform faults

Fault plane solutions along the Mid-Atlantic Ridge

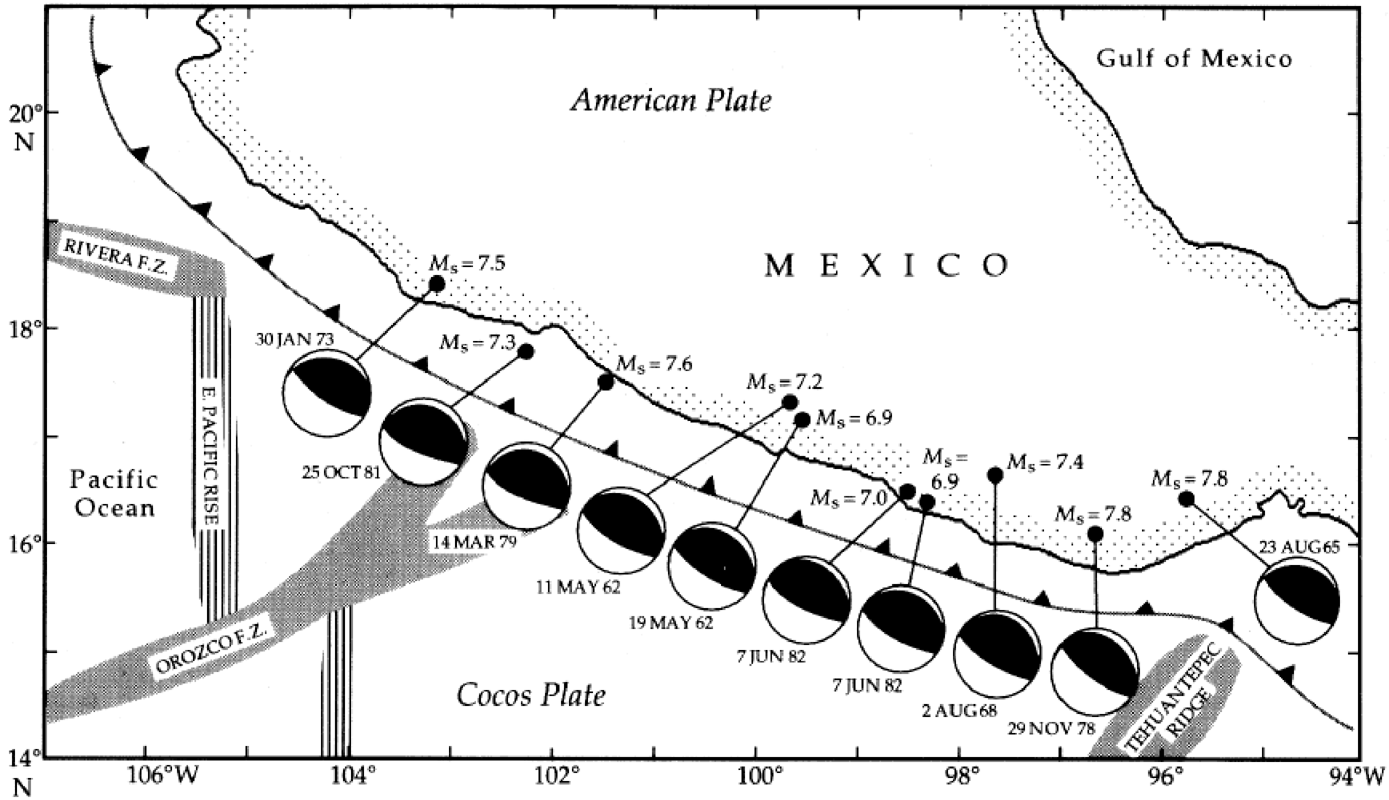


Fault plane solutions for earthquakes on the St. Paul, Romanche, Chain transform faults, central Atlantic Ocean



I. Destructive plate boundaries

a) Subduction zone 1



FPS for shallow earthquakes along Mexico´s west coast

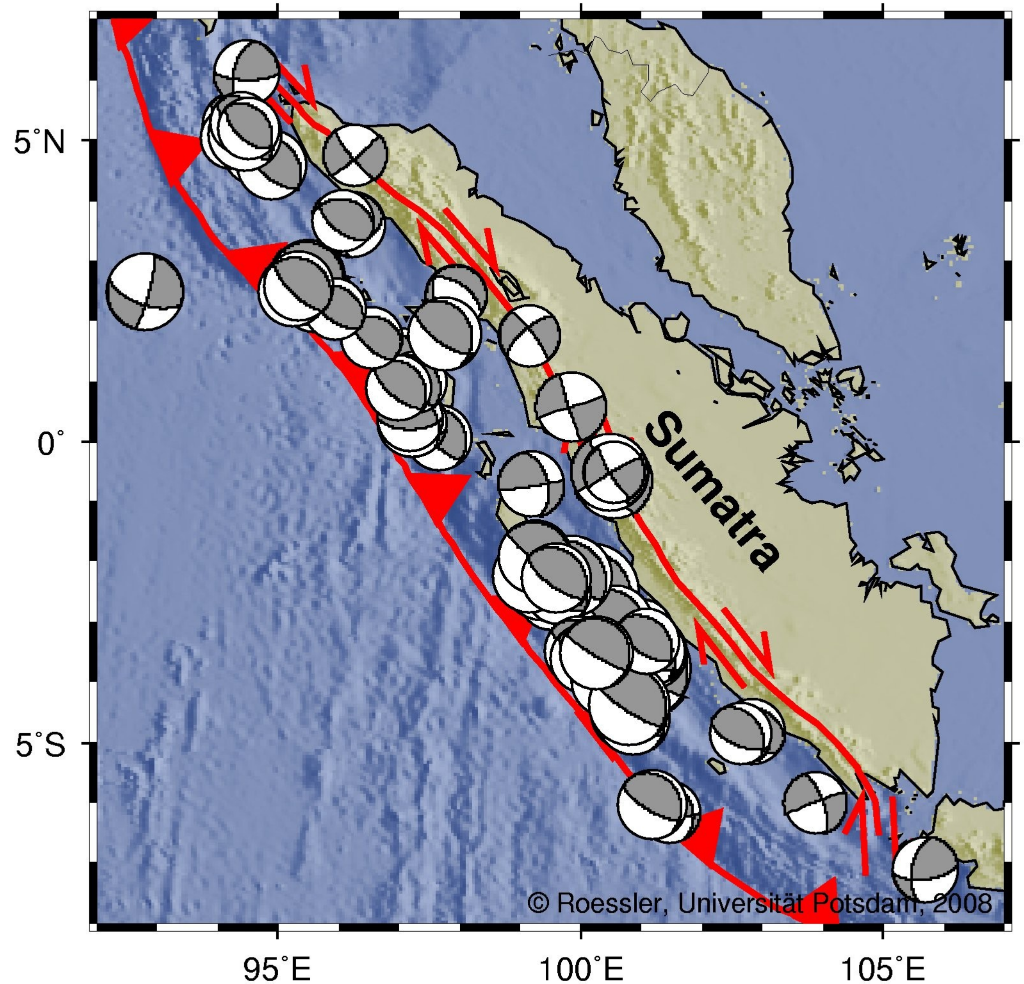
Fault plane roughly parallel to plate margin

Different kinematics in depth:

- Near surface: normal faults
- Moderate depth: stress by direct contact causing low angle thrust
- Deeper: plates decoupled, slab pull dominates causing normal fault
- Very deep: down dip compression

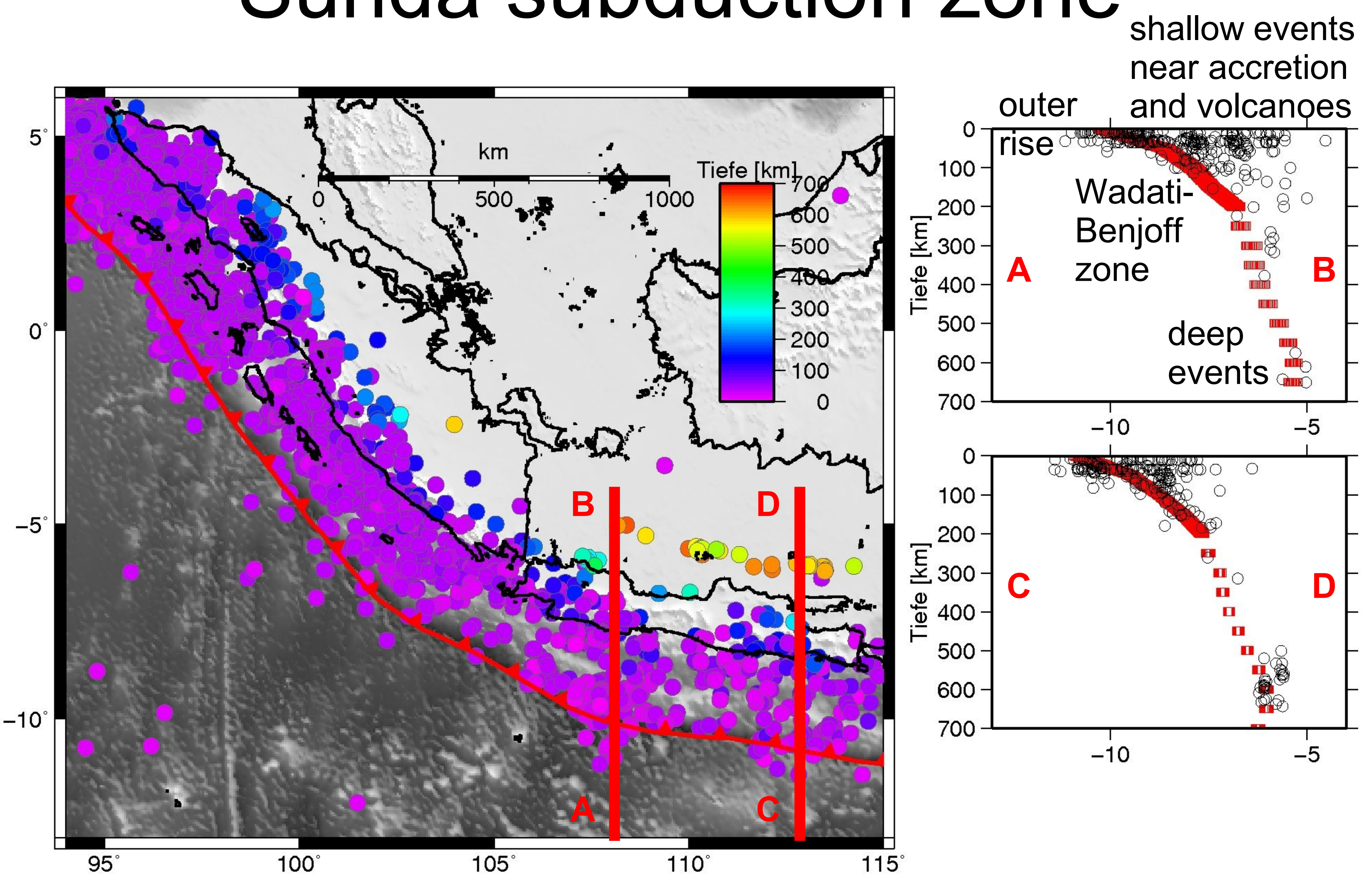
I. Destructive plate boundaries

a) Subduction zone 2

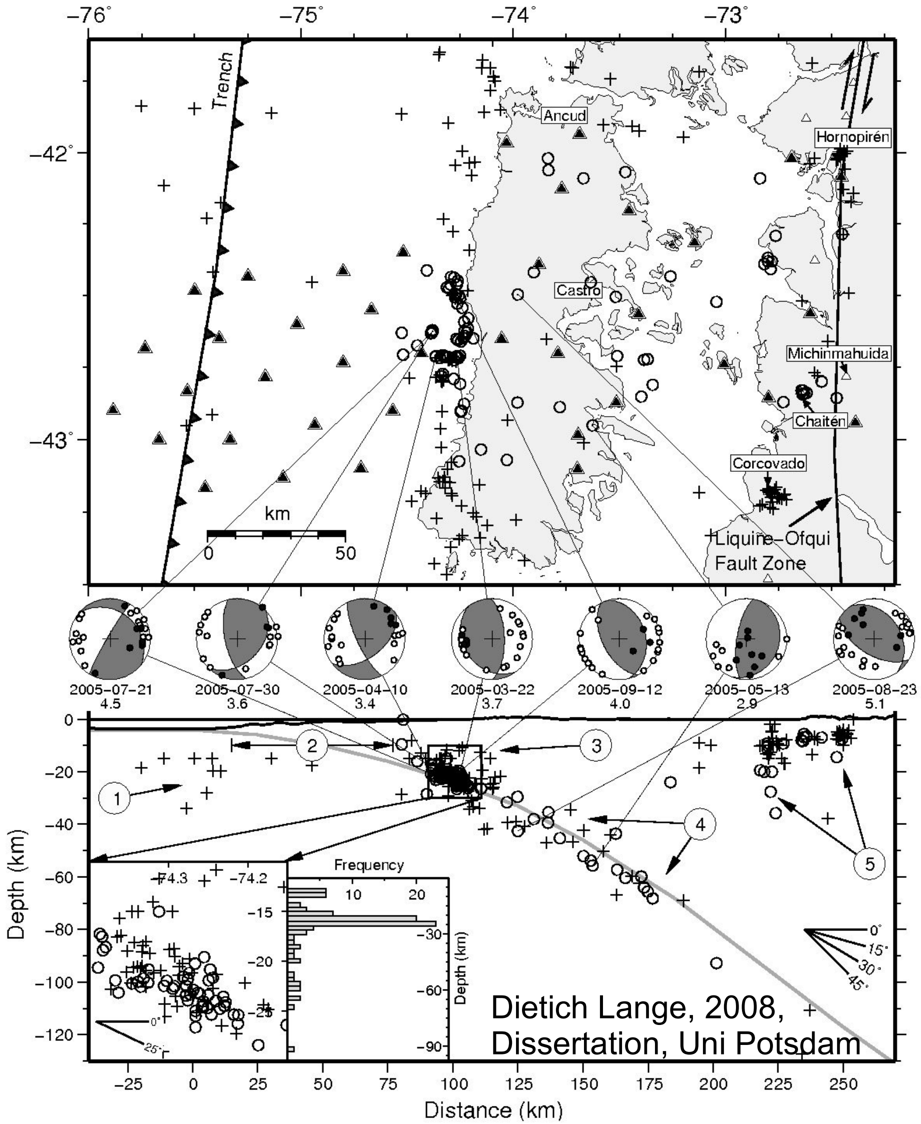


- Fault plane roughly parallel to plate margin
- Strike-Slip faults due to slip partitioning

Sunda subduction zone

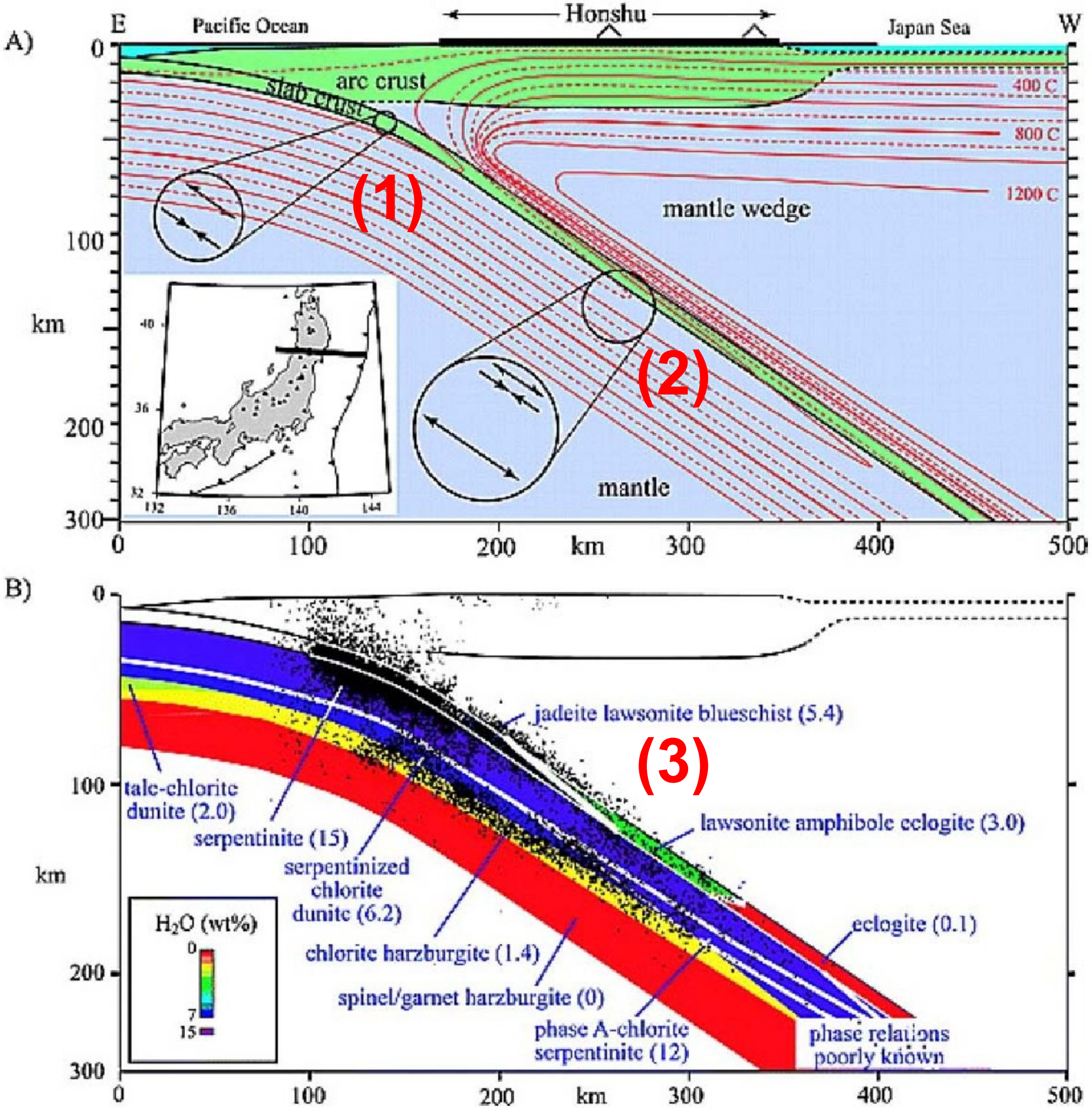


Chiloe (S Chile), subduction



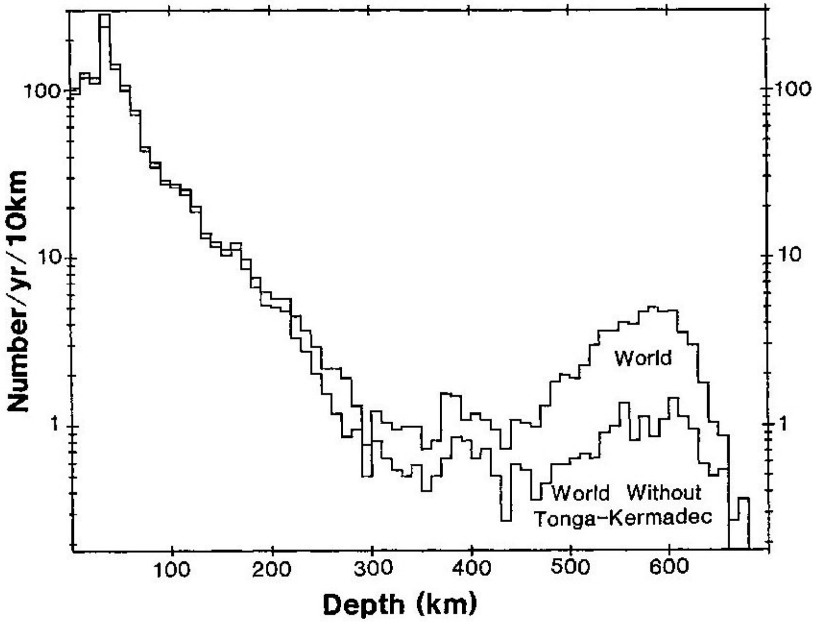
- subduction of Pacific plate underneath S-America
- (1) outer rise earthquakes
- (2) aseismic zone
- (3), (4) Wadati Benioff Zone, thrust events
- (5) strike-slip events near volcanoes
- Strike-Slip faults due to slip partitioning

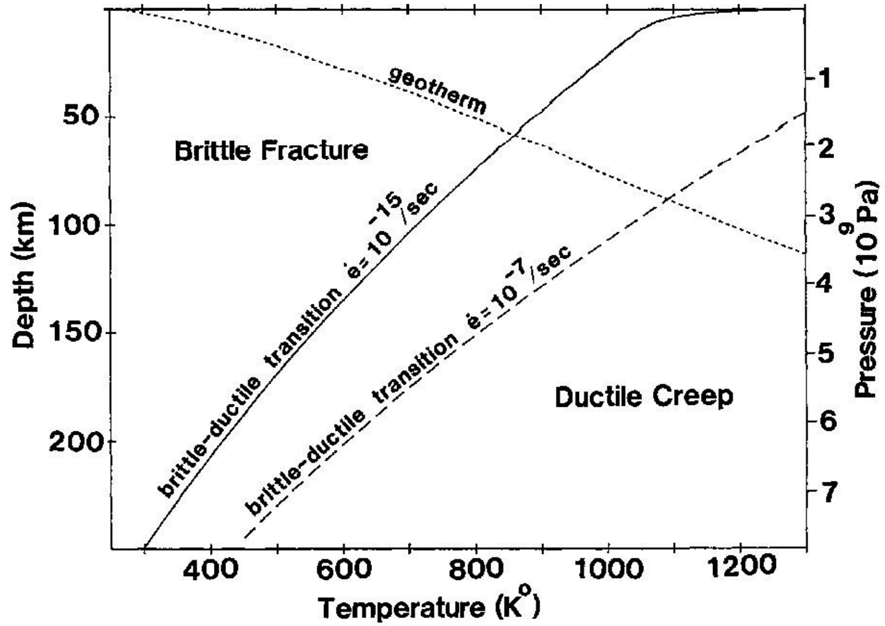
Honshu, Japan



- subduction of Pacific plate underneath Japan
- (1) thrust + reverse faulting - slab push
- (2) normal faulting - slab pull
- (3) Wadati zone as double-seismic zone marks top and bottom of slab

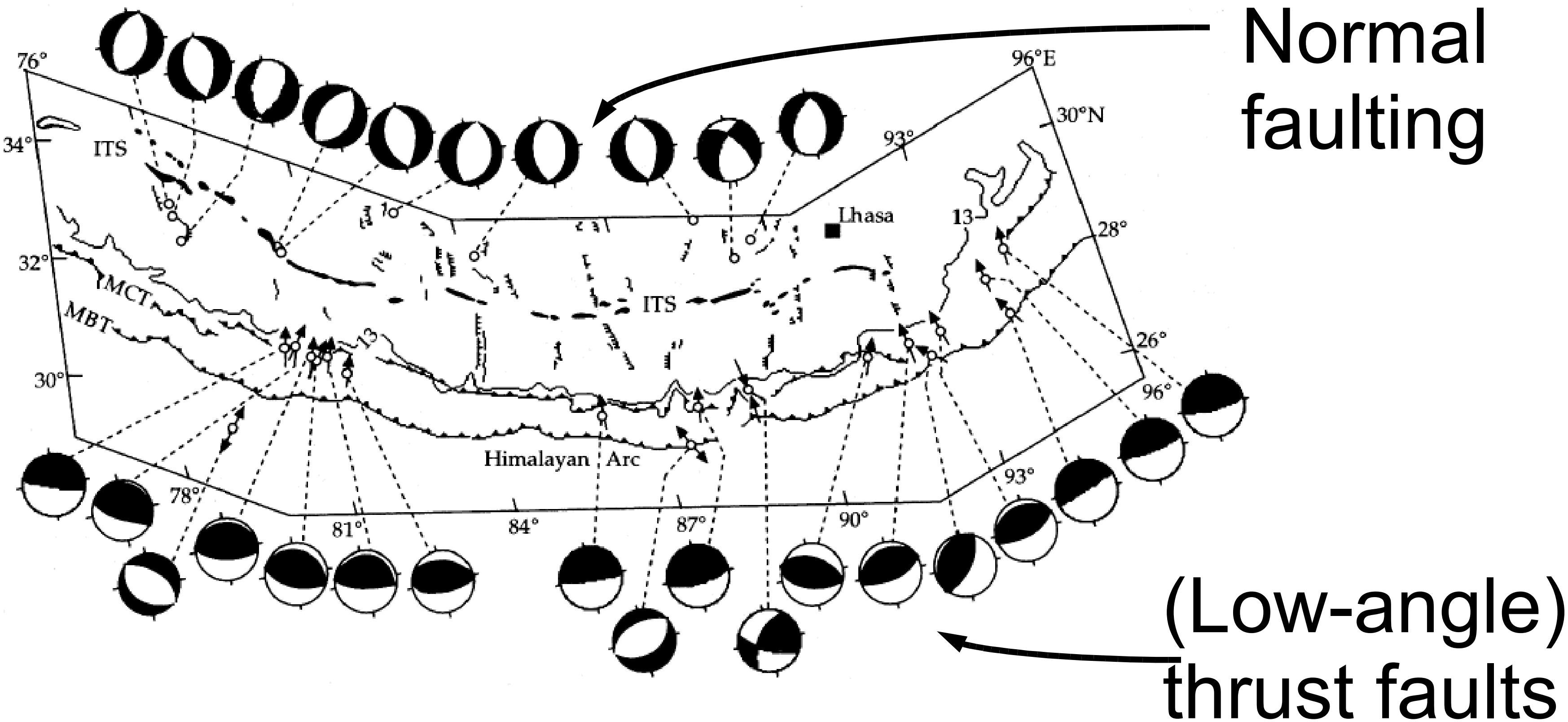
Deep earthquakes





- **above 300 km:** exponential decrease of earthquakes with depth
- **below 300 km:** increased seismicity down to 700 km (subduction) contradicts rheology

b) Continent-continent collision: Himalaya



ITS = Indus–Tsangpo Suture
MCT = Main Central Thrust
MBT = Main Boundary Thrust
13 = 13,000 ft elevation contour

slip direction on low-angle thrust fault
extensional directions on normal fault

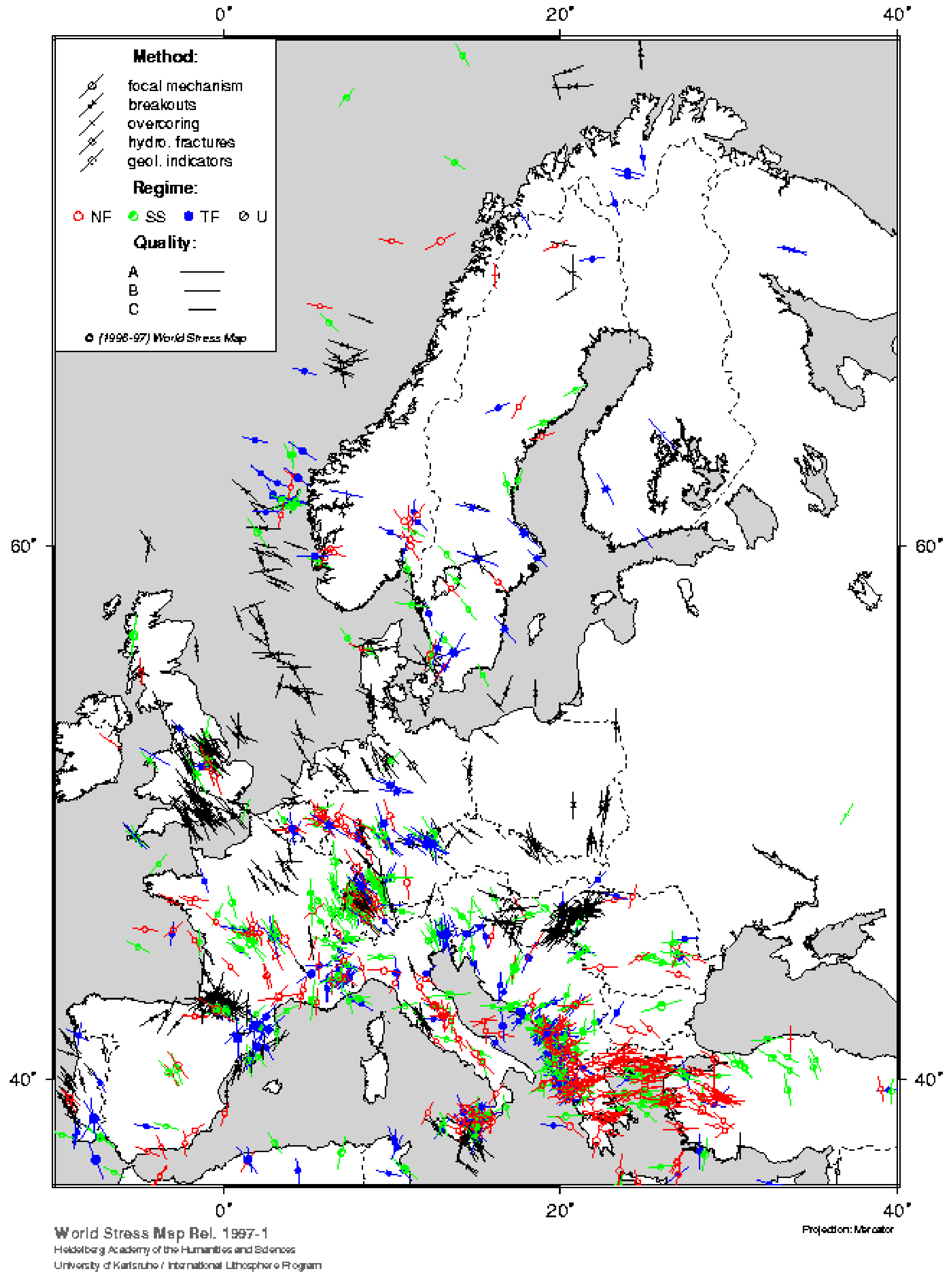
Intraplate seismicity and stress field

Europe / Germany

European stress map

SHmax

- No direct correlation between S_{Hmax} and topography
- Apennin, W-Alps: **NF**-regime correlates with topography, extension normal to mountain range



European stress map

W- and NW Europe:

- Mainly **Strike-Slip Regime (SS)**

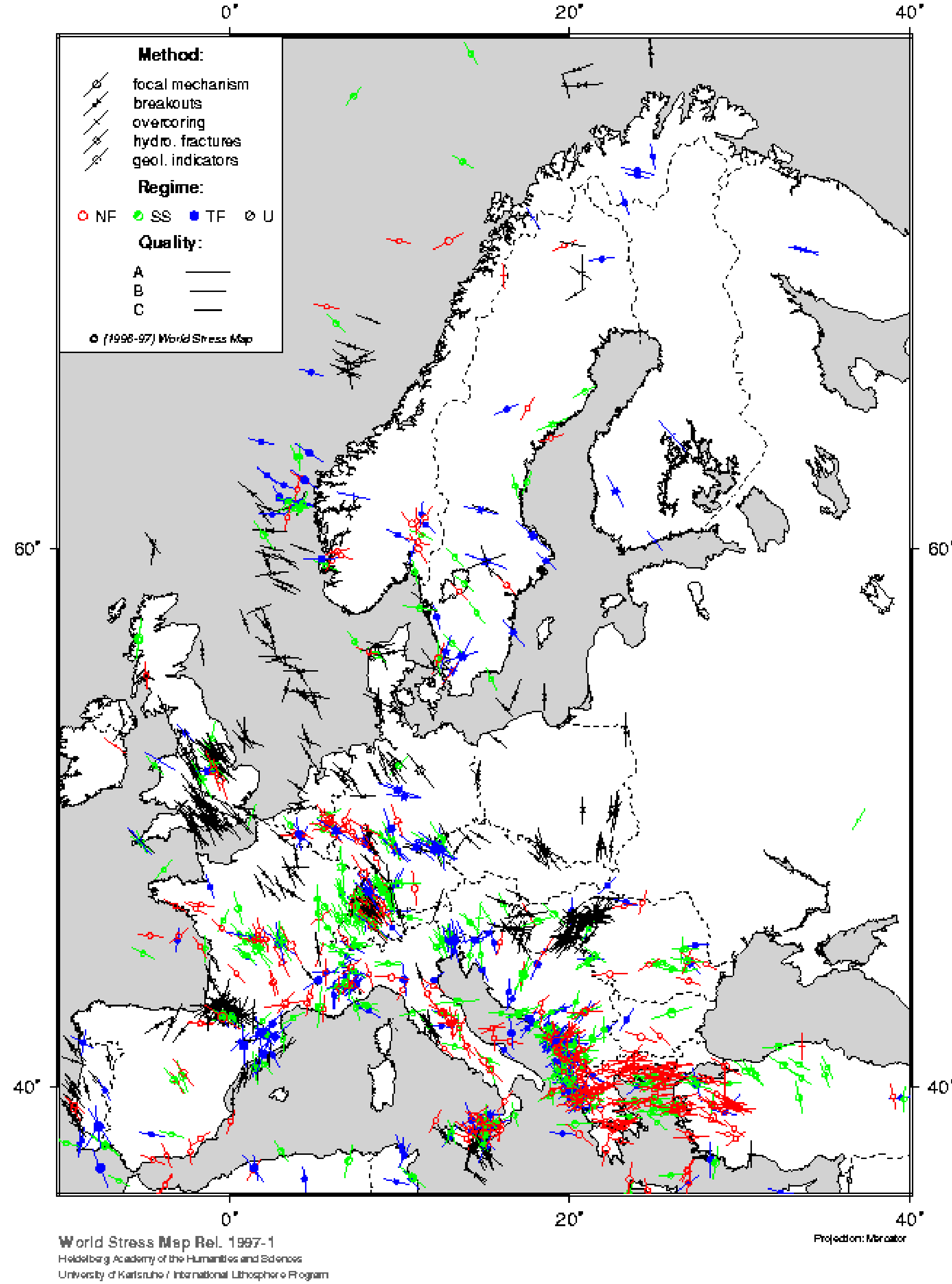
  NW-NNW compression

  NE-ENE extension

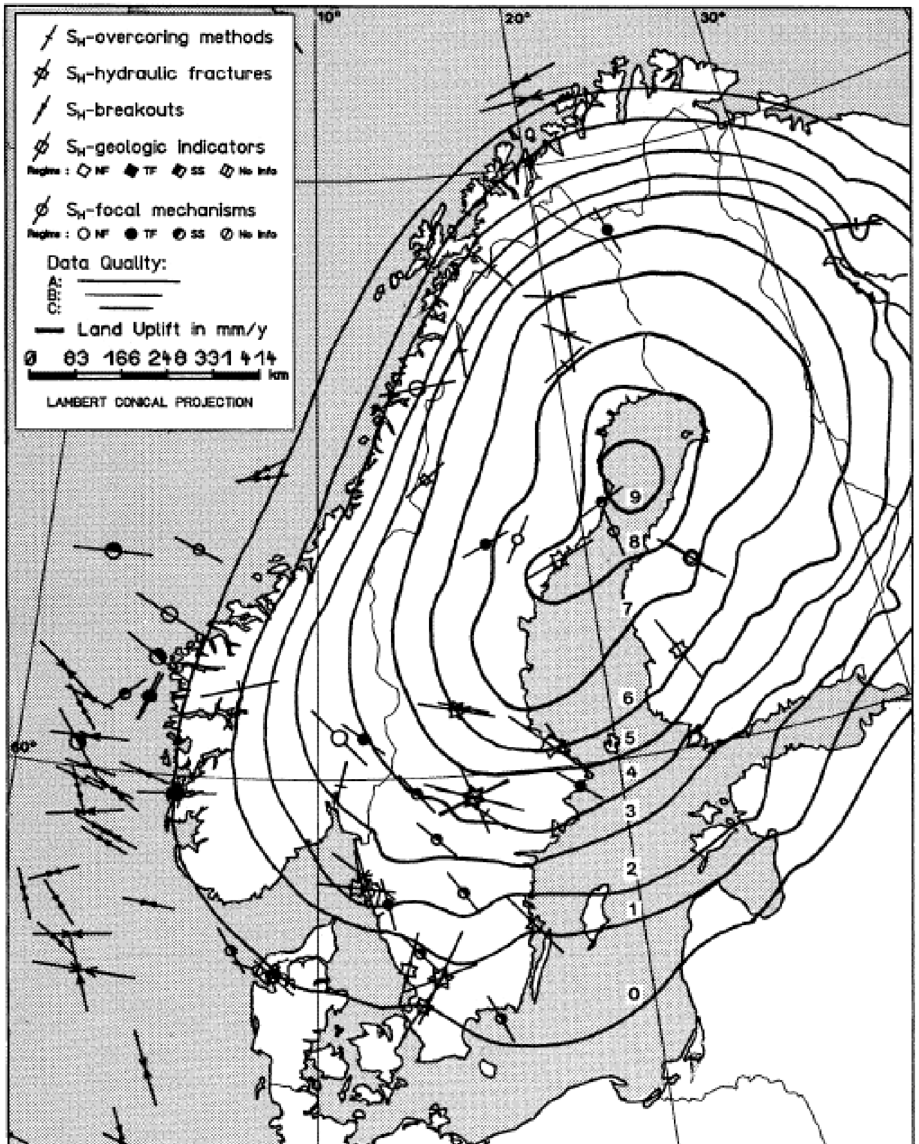
Extensional areas (NF):

- Aegean sea
- Western Anatolia
- Lower Rhine
- Graben
- W-Apennin

\- Parts of France



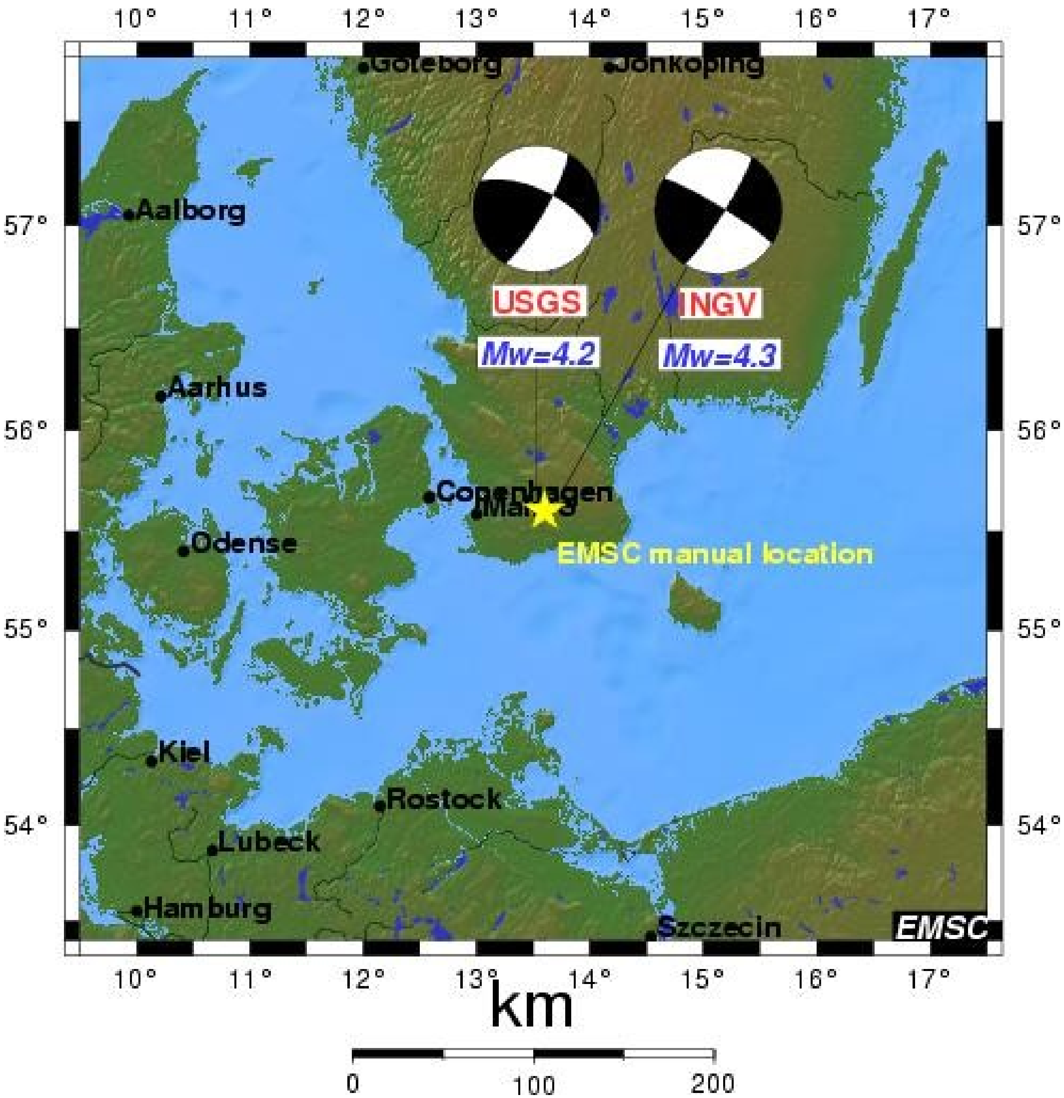
The Northern European stress province



- > 55° N
- Lithosphere thickness 110 – 170 km
- Heat flow < 50 mW/m²
- Isostatic uplift - postglacial rebound
- Large scatter of stress orientation

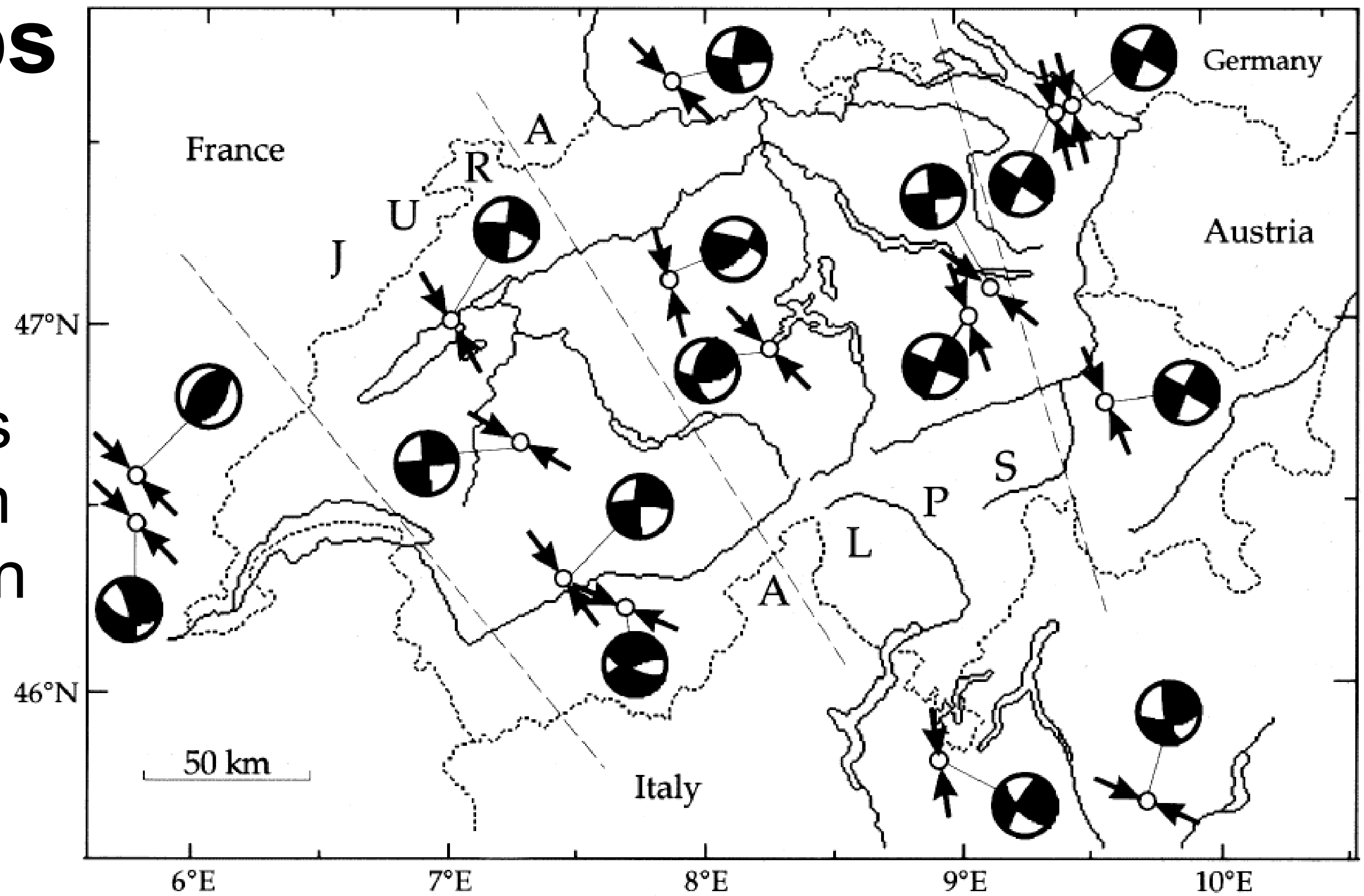
S_{Hmax} orientations & uplift rates

The Northern European stress province



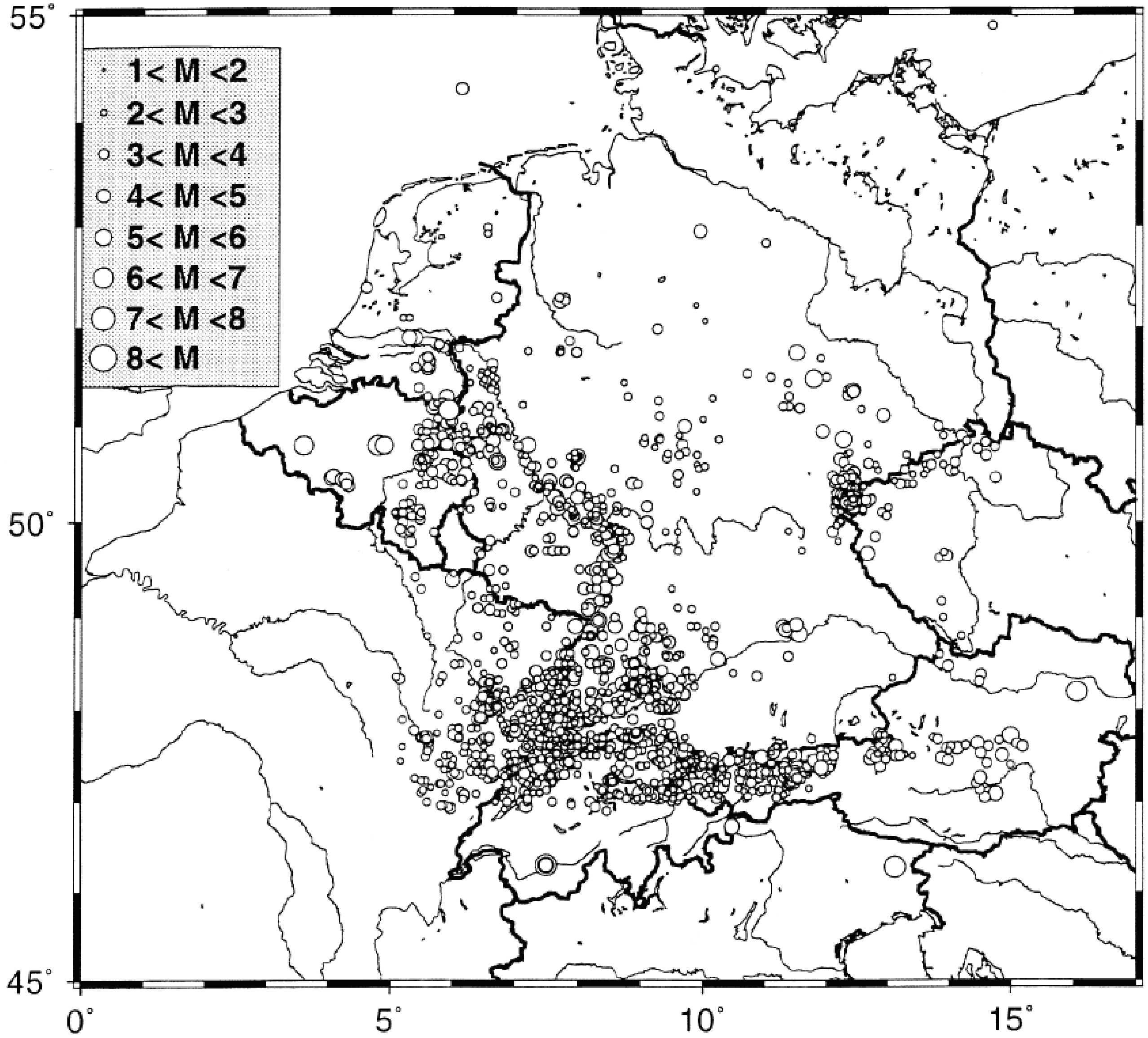
- M4.9 (GEOFON) on 16.12.2008
- strike-slip with reverse component
- result of post-glacial rebound?

The Alps



Mainly strike slip with max. principal stress perpendicular to the Alps´s strike

Seismically active regions in D



- Swabian Jura
- Rhinegraben
- Vogtland
- Alps
- Franconian Jura
- Saxonia (Gera-Jachimov)

Erdbeben 1000-1994

Swabian Jura earthquakes

- 16.11.1911 Ms ~ 5.6 MWA ~ 6.1 z 10 [km]
- 28.05.1943 Ms ~ 5.5 MWA ~ 5.5 z 8 [km]
- 03.09.1978 Ms ~ 5.1 MWA ~ 5.7 z 6.5 [km]

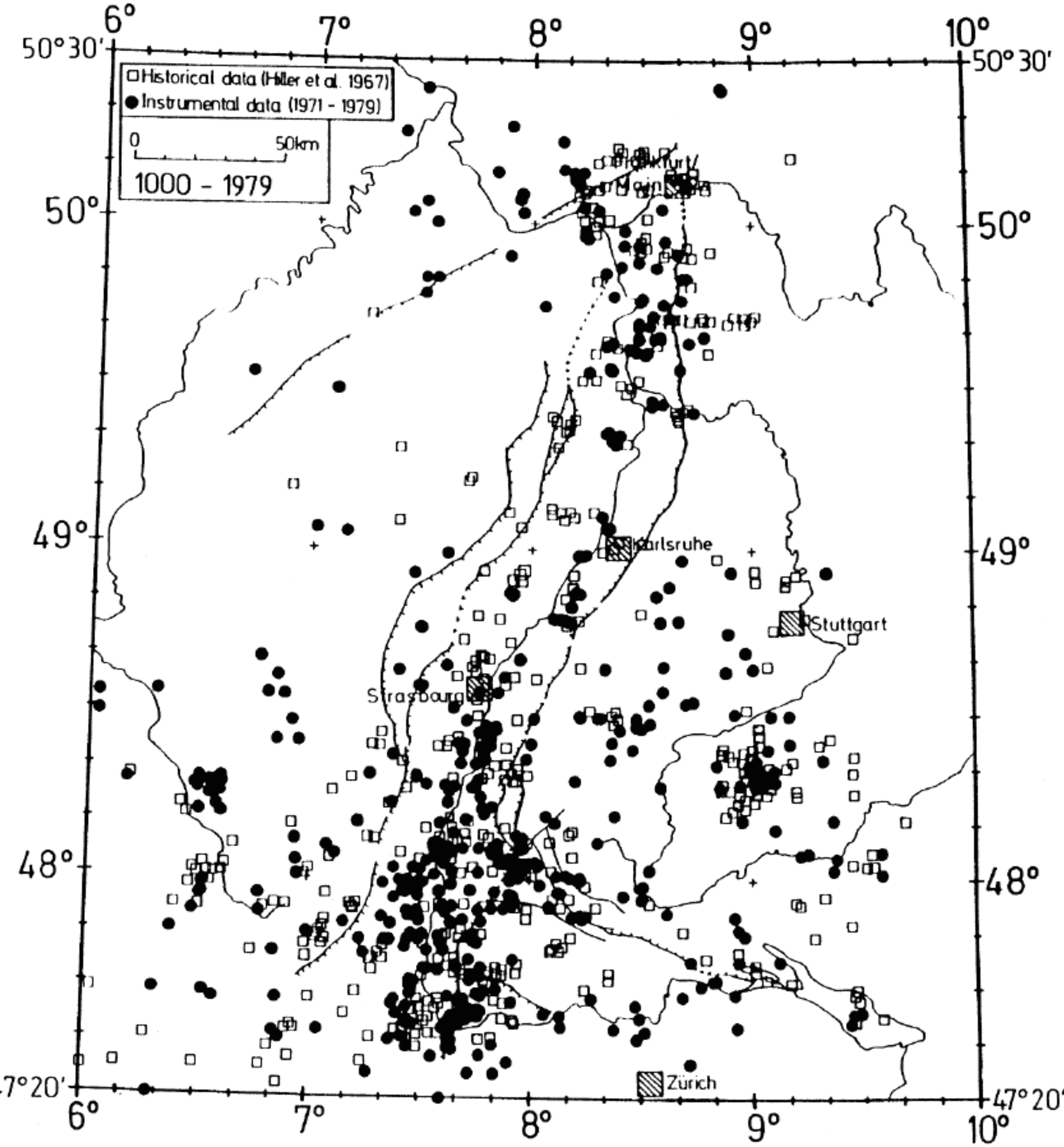
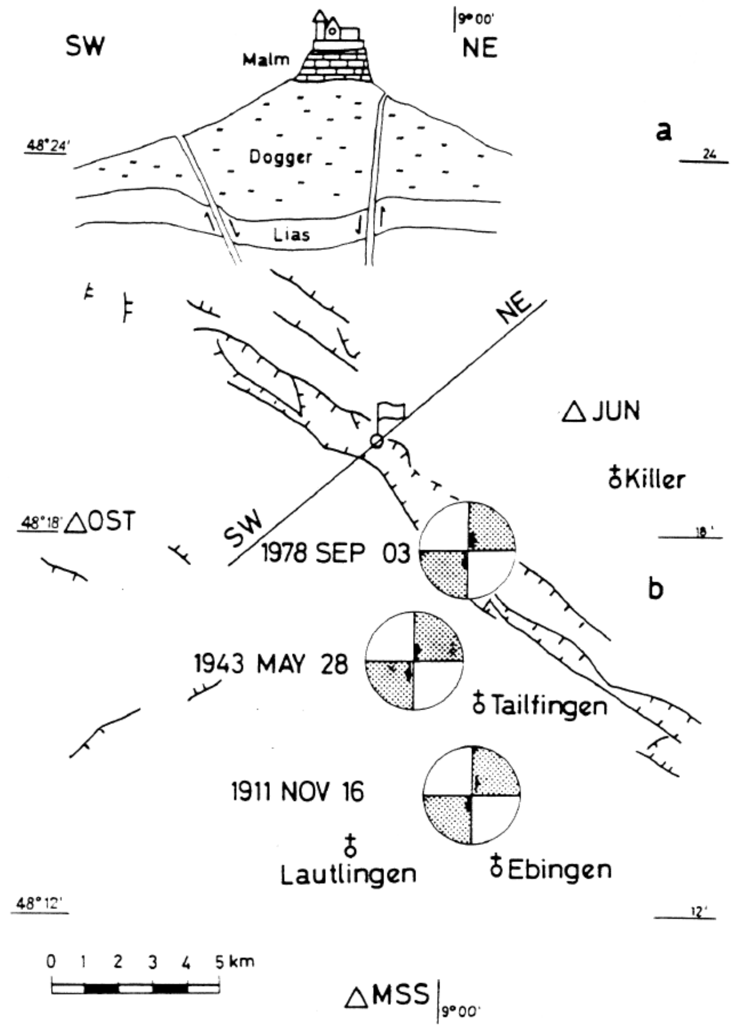


Fig. 7. Comparison between historical and present day seismic activity. *squares:* historical (mainly macroseismic) epicentres (1000–1970); *circles:* instrumentally determined epicentres (1971–1980)

Fault mechanisms



Aftershock distribution

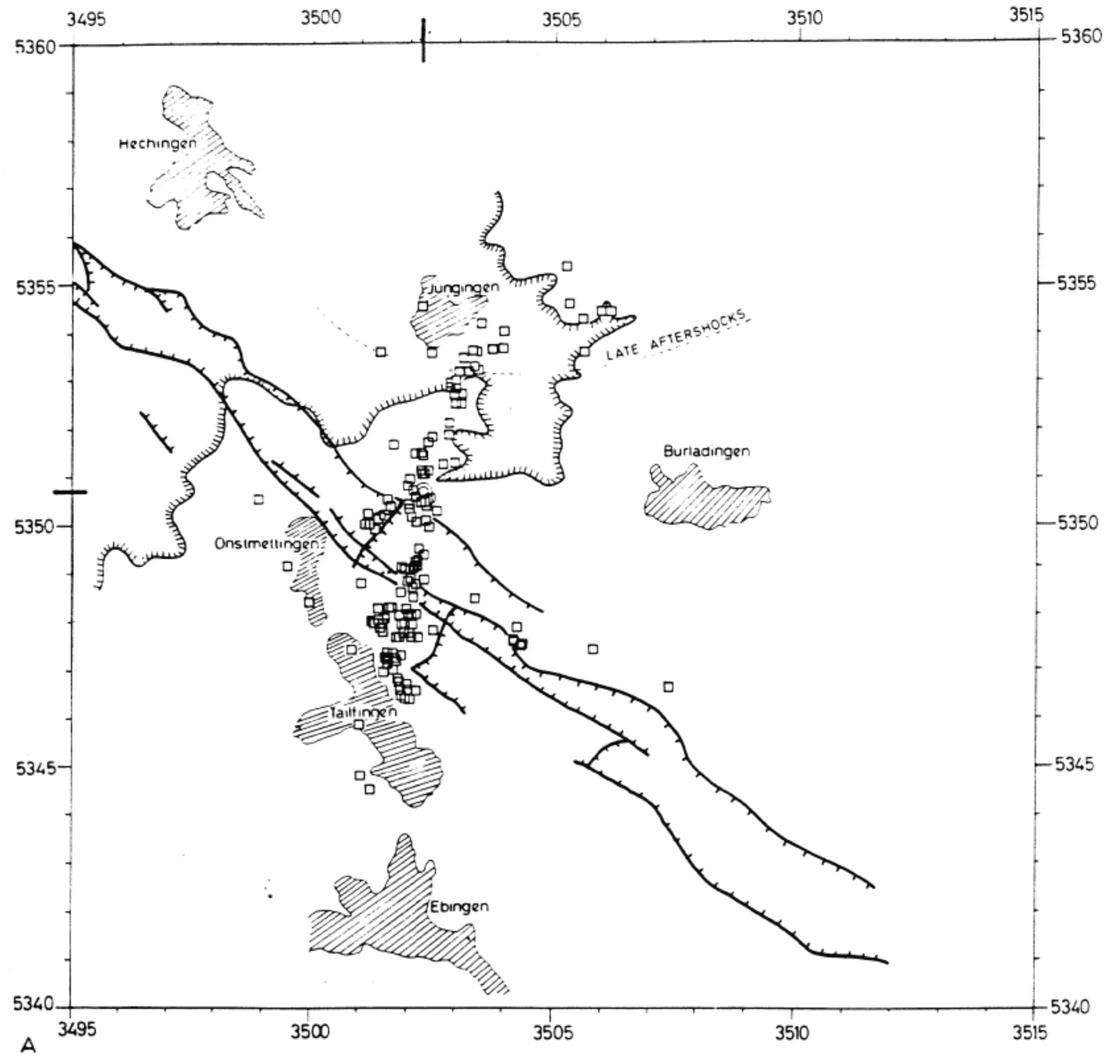


Fig. 7. A. Epicenters of aftershocks (main shock illustrated by circle). B. Hypocenters of aftershocks in N—S cross-section (main shock illustrated by circle). C. Hypocenters of aftershocks in E—W section (main shock illustrated by circle).

Composite focal mechanism

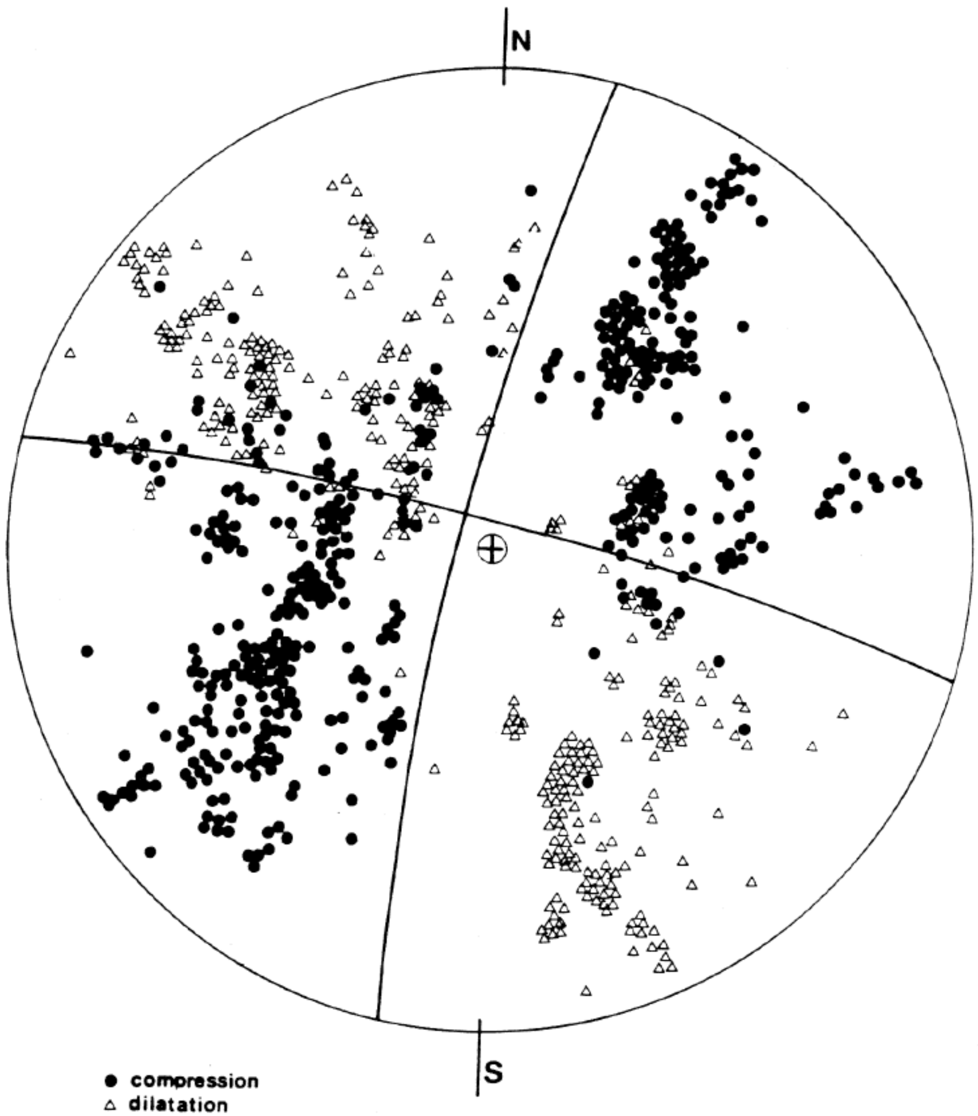
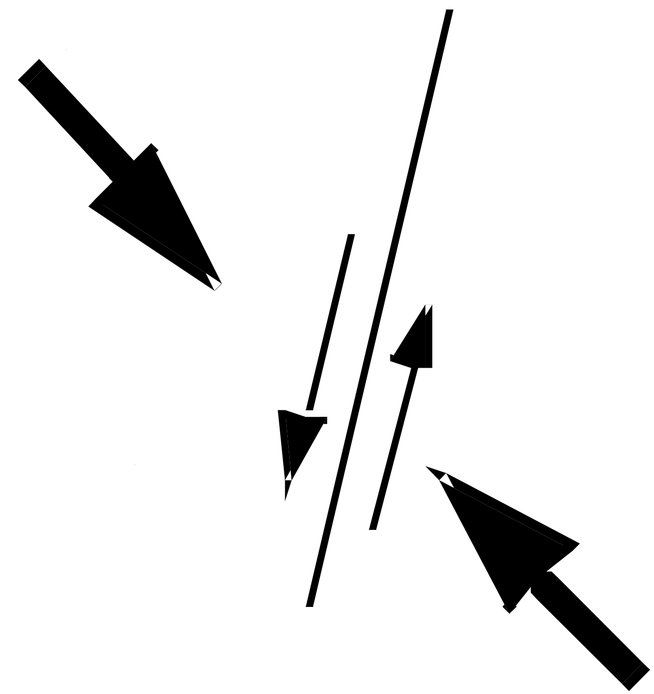


Fig. 8. Composite fault-plane solution of aftershocks (WULFF net, *upper focal hemisphere*).



Lower and upper Rhine Graben

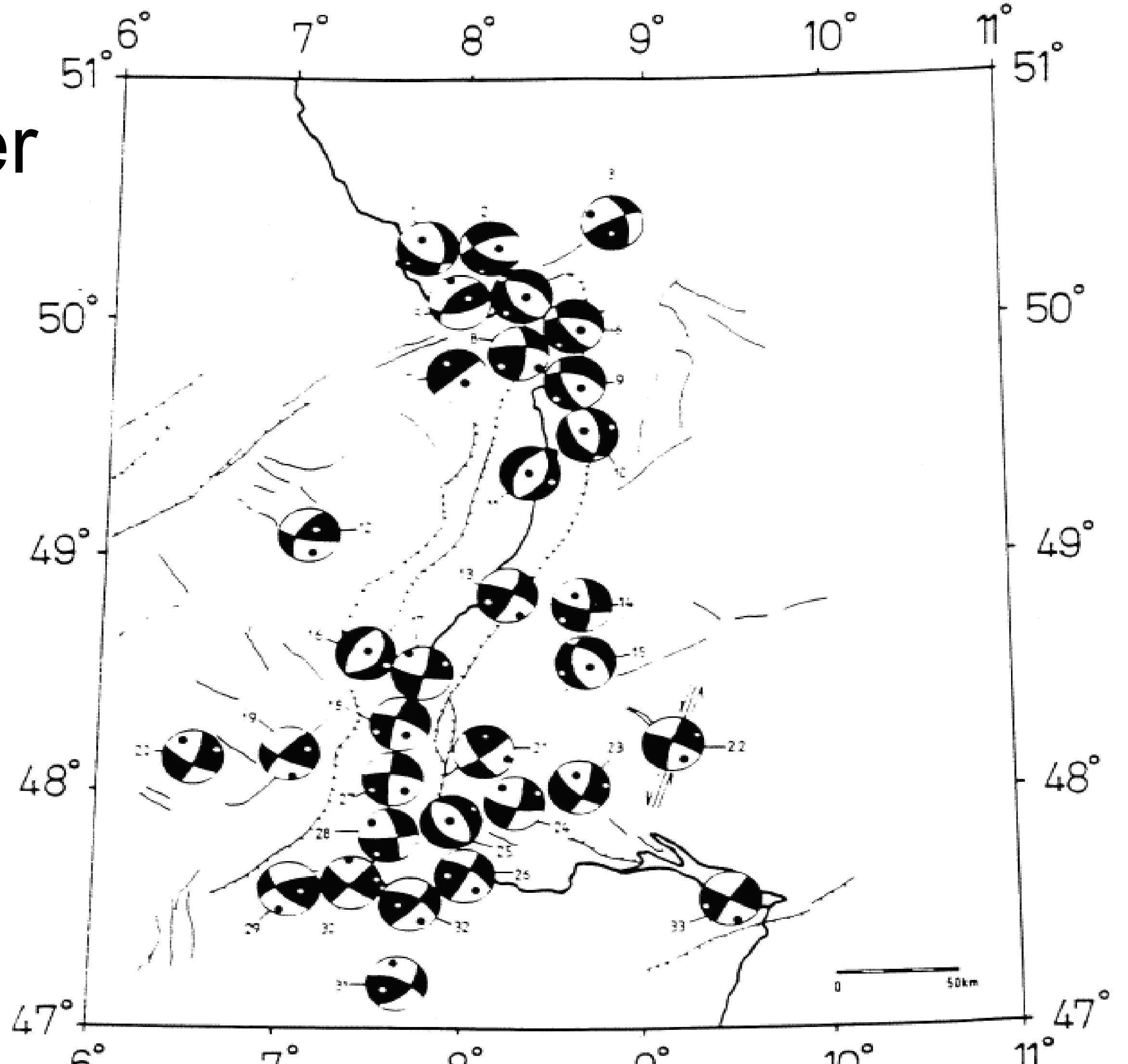


Fig. 11. Fault-plane solutions (Wulff projection) in the Upper Rhinegraben area. (References: [1, 5, 6, 8, 9, 21, 23, 24, 27] = Ahorner et al., 1983: [3] = Neugebauer and Tobias, 1977; [4] = Baier and Wernig, 1983; [22] = Turnovsky, 1981; [31, 33] = Mayer-Rosa and Pavoni, 1977; [2, 7, 10–20, 25, 26, 28–30, 32] = this paper). *Black quadrants:* compression. *White quadrants:* dilatation. *Black dots: P*-axes. *White dots: T*-axes

Depth distribution

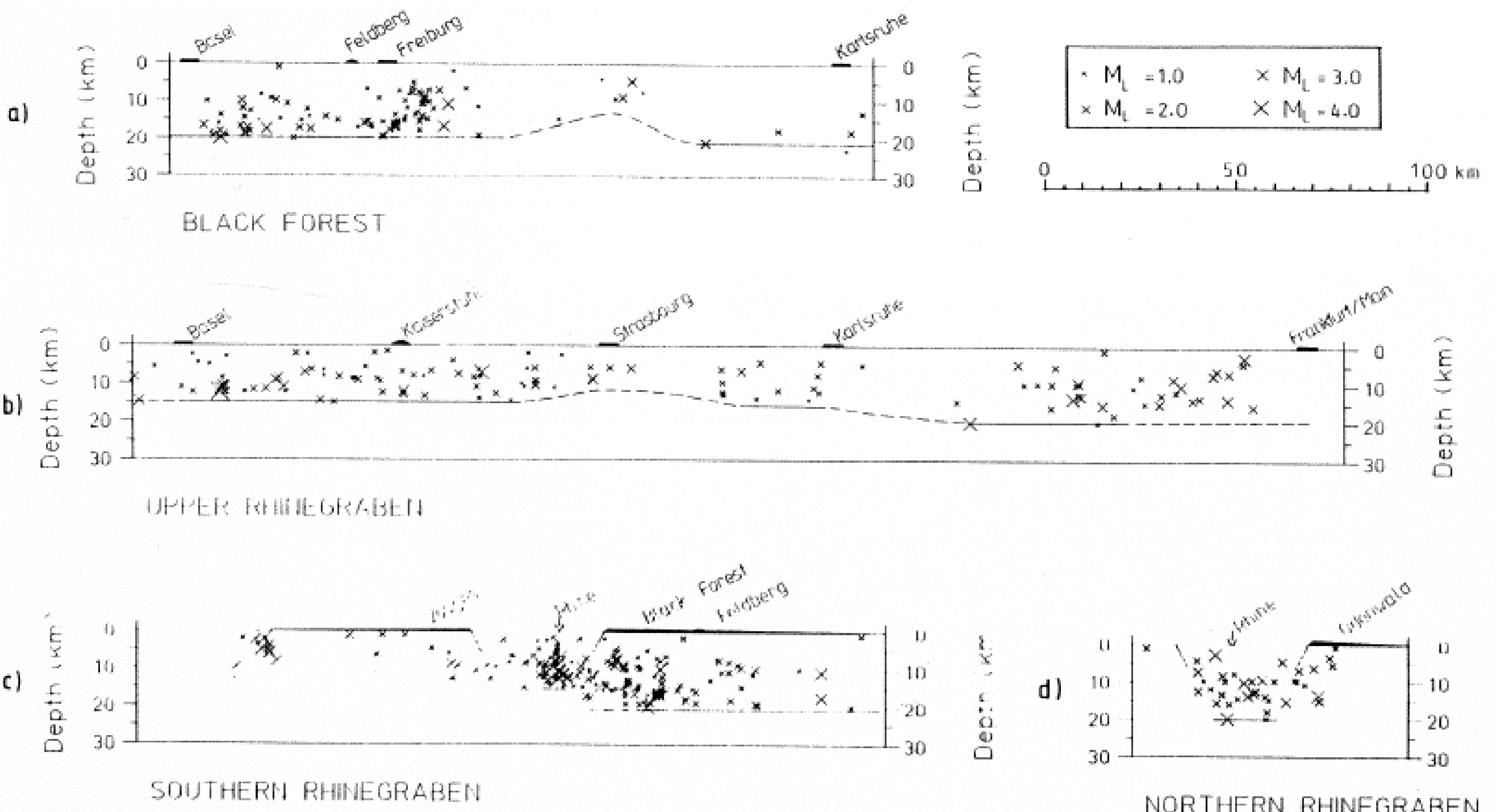


Fig. 9 a–d. Depth distribution of foci (1971–1980). Cross section **a**: Black Forest, parallel to the strike of the graben; **b**: graben proper, average strike direction N20° E; **c**: perpendicular to the strike of the southern graben. Hypocentres between Strasbourg and Basel were projected; **d**: northern graben, strike direction approximately EW. The boundaries of greatest focal depths are marked by *solid lines*

Lower Rhine Embayment and Roermond earthquake (13.04.1992 M ~ 6.0)

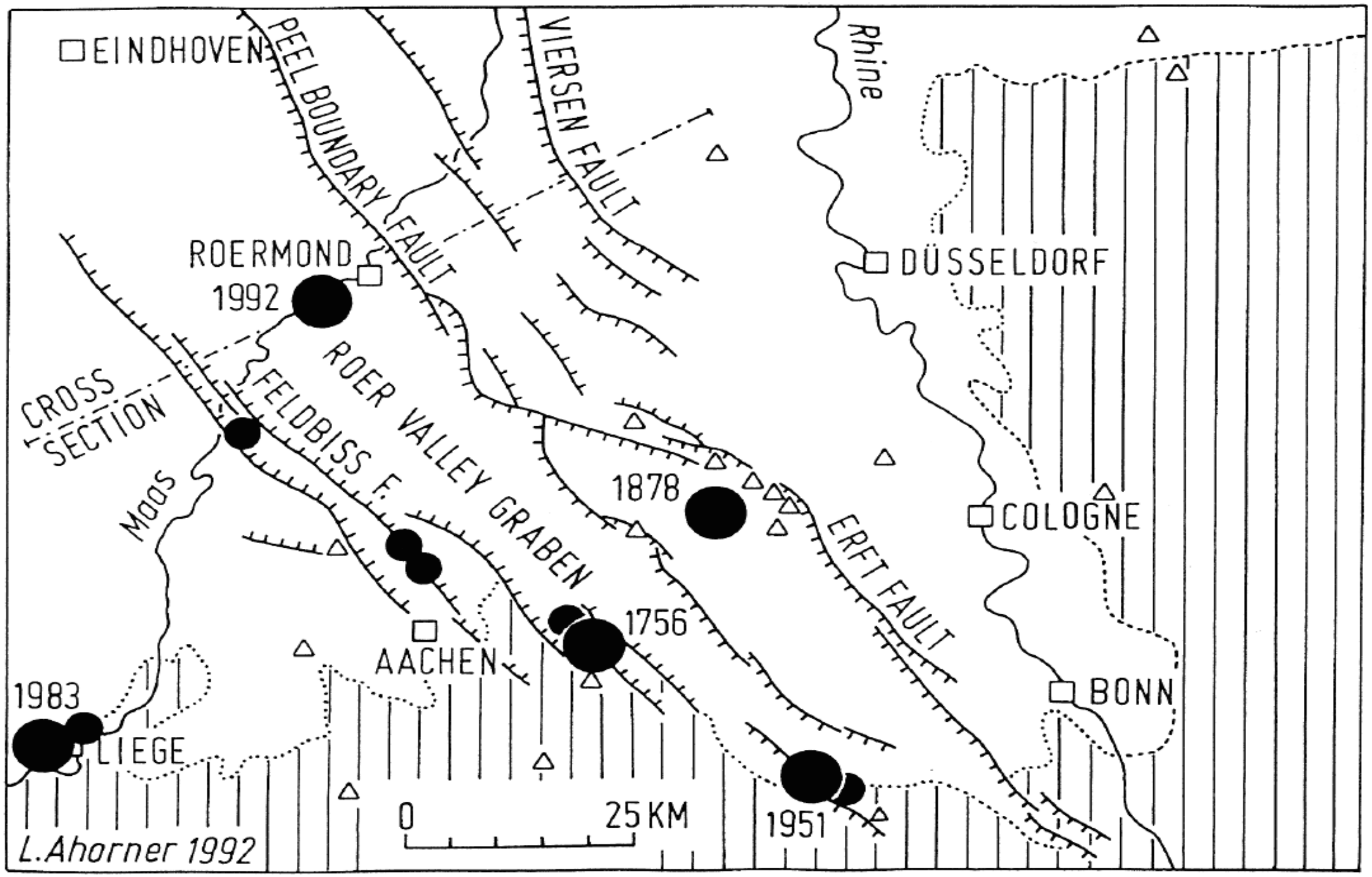


Fig. 1. **Sketch map of the Lower Rhine Embayment with the epicenters of damaging earthquakes (filled circles) since 1750. For larger events with local magnitudes $M_L > 5.0$ (big circles) the year of occurrence is denoted. Active normal faults are drawn with barbs on the downthrown side (after Ahorner 1962). Permanent seismic stations are displayed by triangles. The cross-section is shown in Fig. 4.**

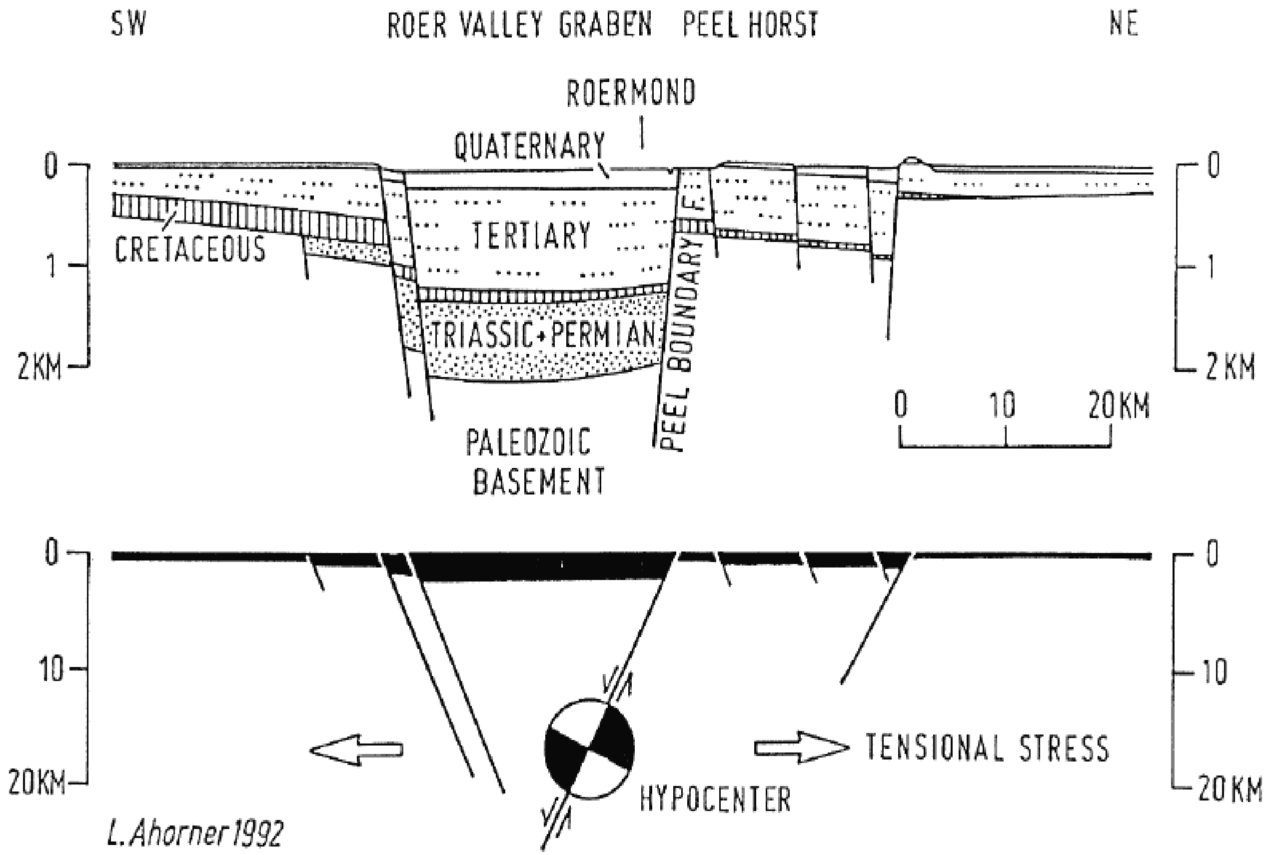


Fig. 4. Simplified geological cross-section through the Roer Valley Graben near Roermond (for location see Fig. 1). The hypocenter of the Roermond mainshock is located on the depth continuation of the Peel Boundary Fault which forms the eastern border of the Roer Valley Graben.

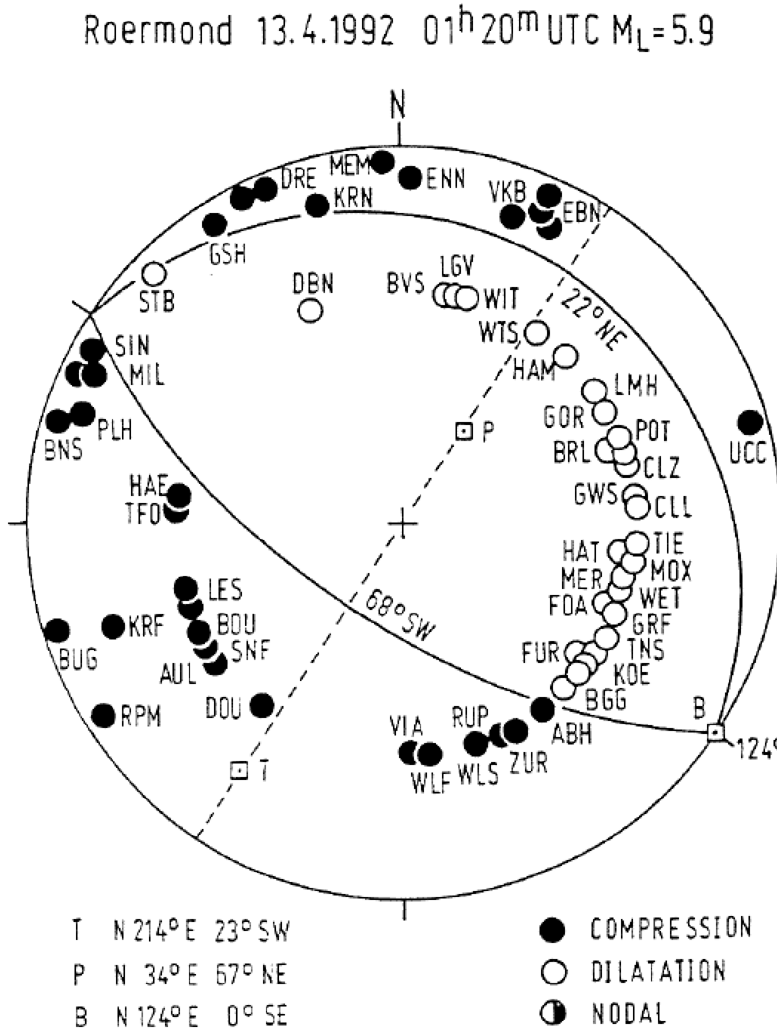


Fig. 5. Fault-plane solution for the Roermond mainshock based on P-wave first motions from local and regional records identified by station code (after Ahorner 1992). Equal-area projection of the lower hemisphere. Take-off angles of the ray paths were calculated using the crustal velocity model of Table 3. P, T and B denote Pressure, Tension and Neutral axis, respectively.

Seismotectonics - Saxony

from: Erdbebenbeobachtung in Sachsen, Dreijahresbericht 2004-2006, Landesamt f. Umwelt und Geologie

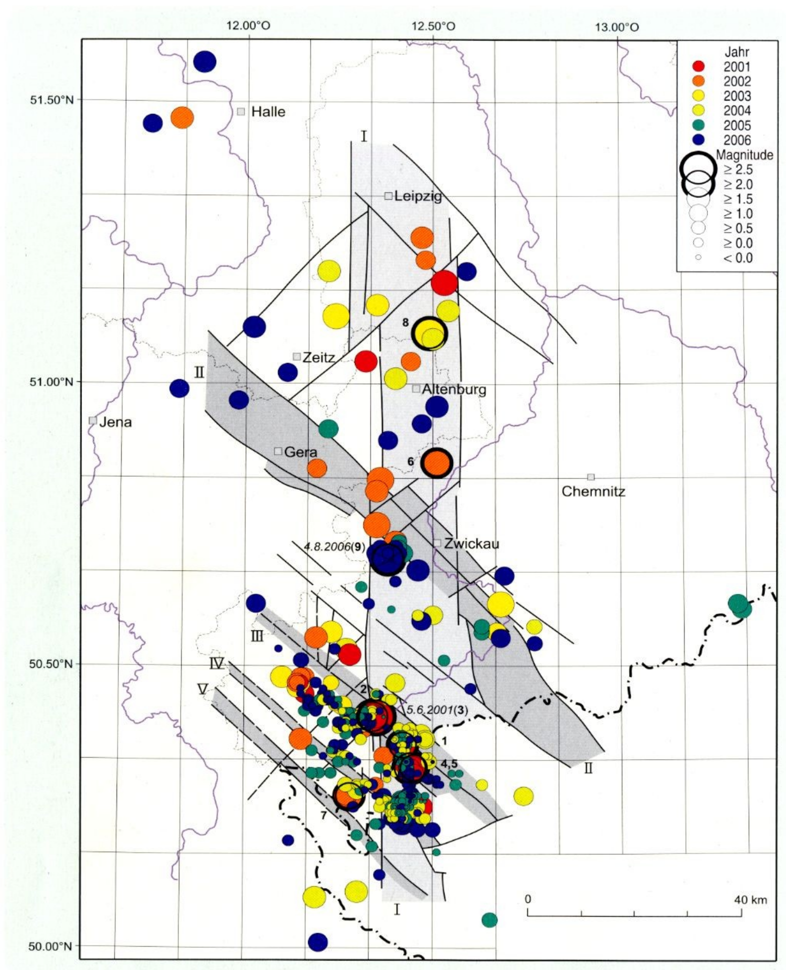


Abb. 14: Verteilung der seismischen Ereignisse in Sachsen und angrenzenden Gebieten im Zeitraum 2001 – 2006 und bedeutende Störungszonen

I	Leipzig-Regensburg Störungszone	IV	Eichigt-Adorf-Luby Störungszone
II	Gera-Jáchymov Störungszone	V	Gefell-Bad-Brambach Störungszone
III	Bergen-Klingenthal-Chodov Störungszone		1 – 5; 8; 10; 19; 36 stärkste Erdbeben vgl. Tab. 5

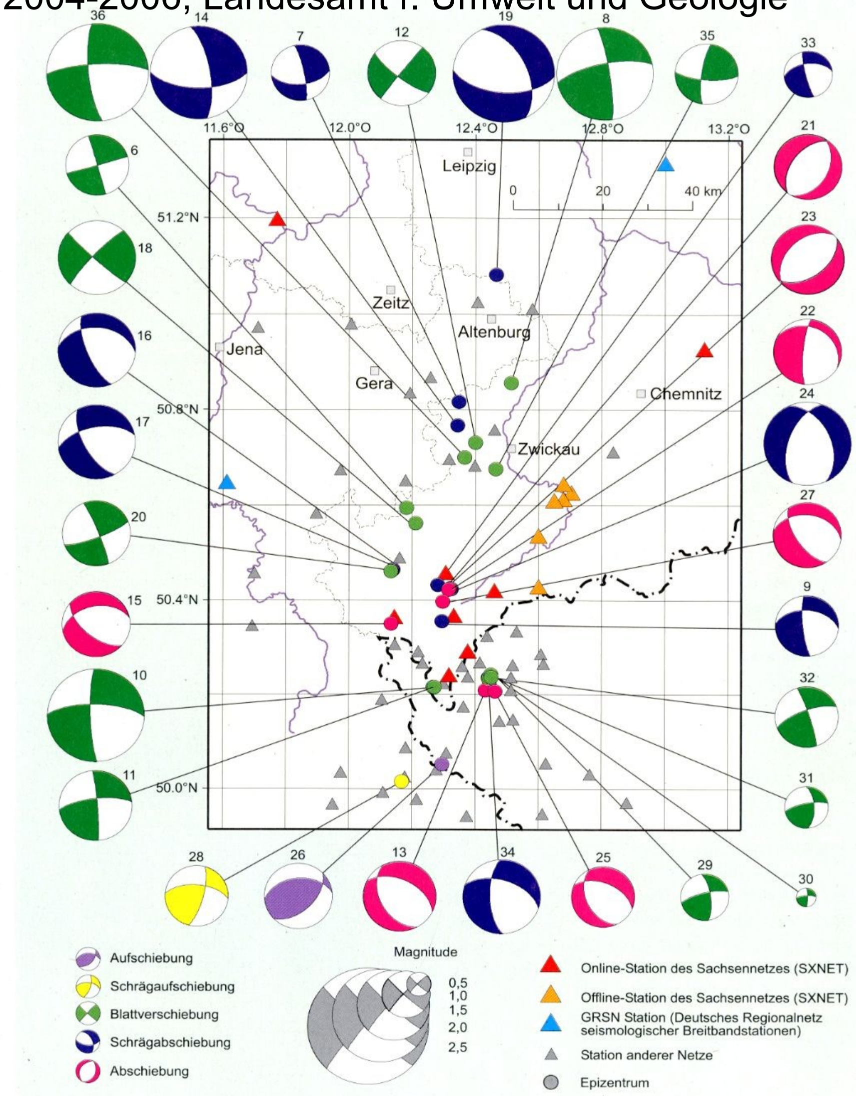


Abb. 21: Epizentren und Herdflächenlösungen für 31 Beben (2002 - 2006)
6 - 36, ausgewählte Erdbeben vgl. Tab. 5

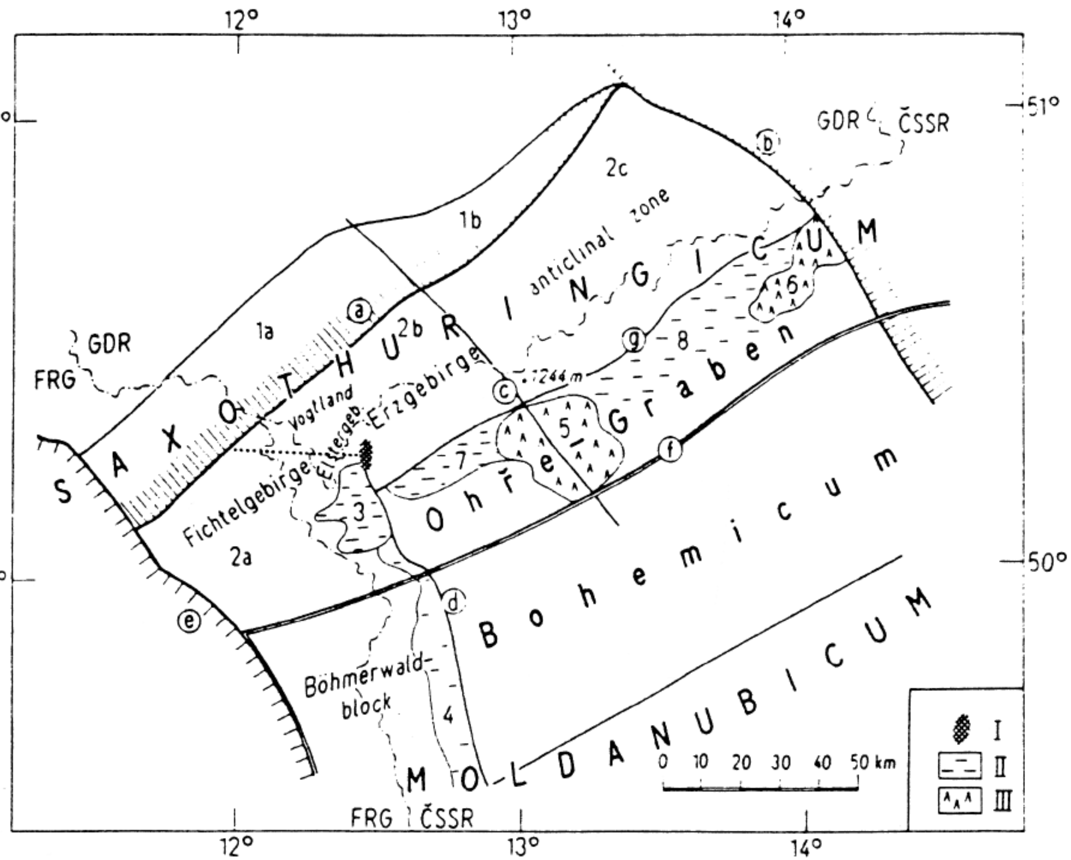
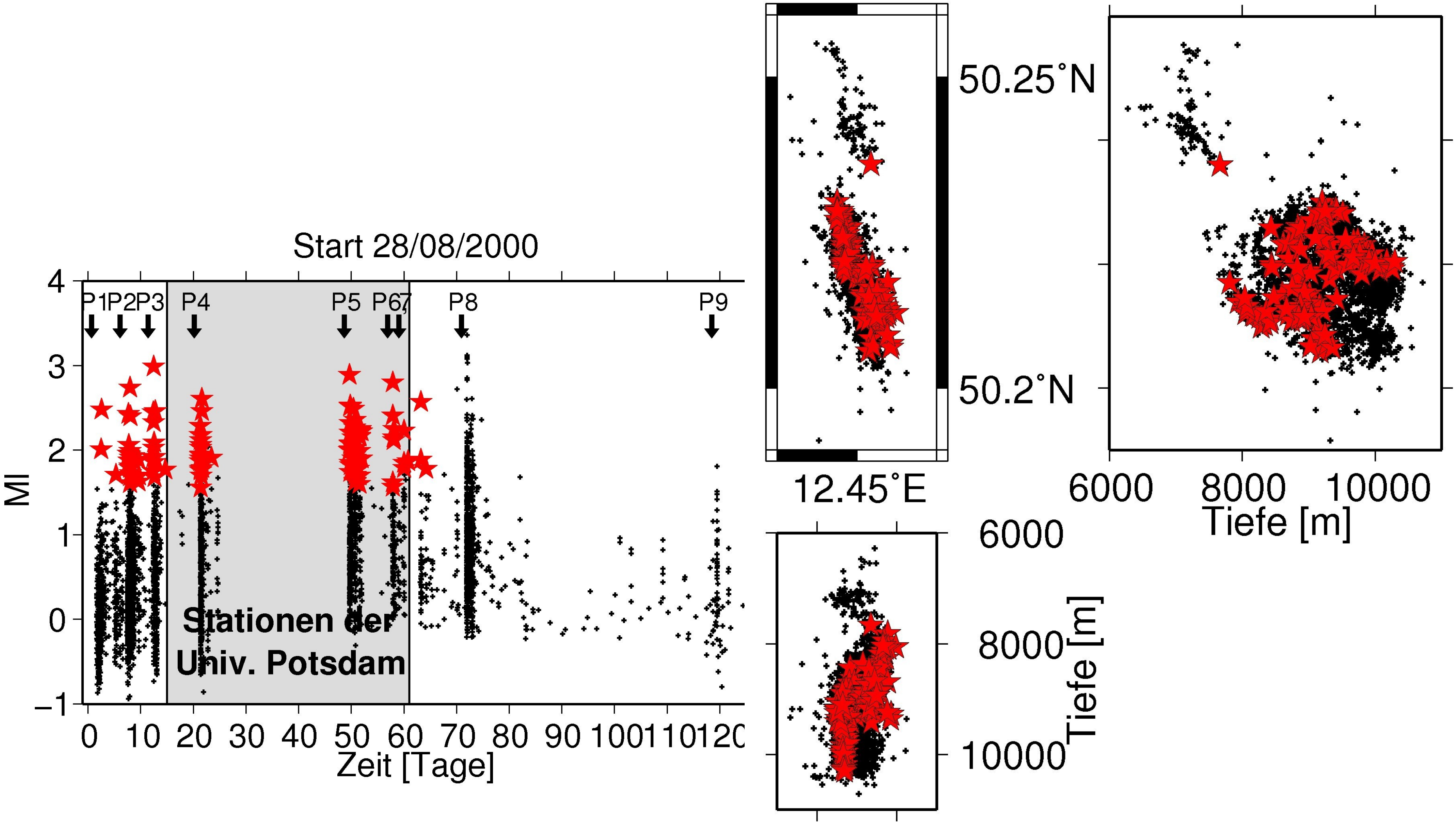


Fig. 3. Principal tectonic and geological units. *I* = focal zone of the 1985/86 swarm. *II* = Tertiary basins. *III* = Tertiary volcanites. *1* —synclinal zone of Vogtland and Central Saxony. *1a*—Vogtland synclinorium. *1b*—central Saxonian synclinorium. *2*—anticlinal zone of Fichtelgebirge and Erzgebirge. *2a*—Fichtelgebirge anticlinorium. *2b*—transverse zone of southern Vogtland and western Erzgebirge. *2c*—Erzgebirge anticlinorium. (*1a* and *2b*—Vogtlandian slate mountains). *3*—Tertiary Cheb Basin. *4*—Tachov-Domažlice Graben. *5*—Doupovské vrchy. *6*—České středohoří. *7*—Sokolov Basin. *8*—Most Basin. *a*—Central Saxonian lineament. *b*—Elbe lineament. *c*—Gera Jáchymov fault zone. *d*—Mariánské Lázně fault zone. *e*—Franconian fault zone. *f*—Litoměřice deep fault. *g*—Erzgebirge fault.

August – December 2000:

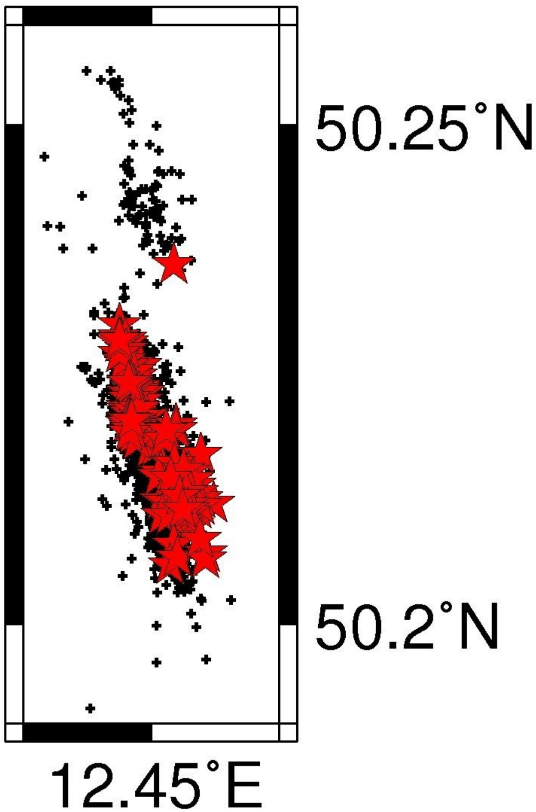
> 10000 Earthquakes

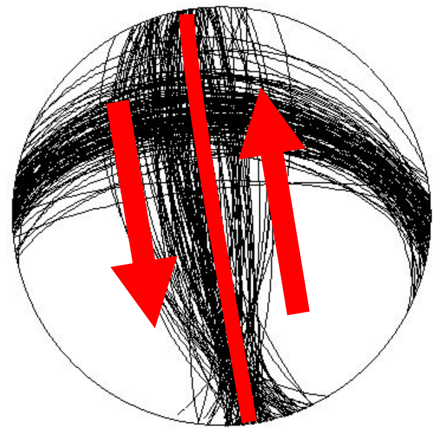


Magnitudes and hypocentres:: T. Fischer, WEBNET

August – December 2000: Fault-plane solutions

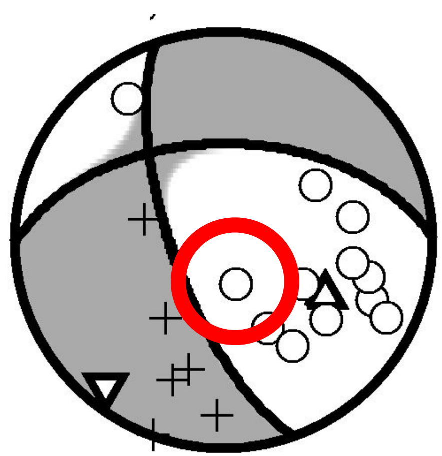
(Roessler, 2006)



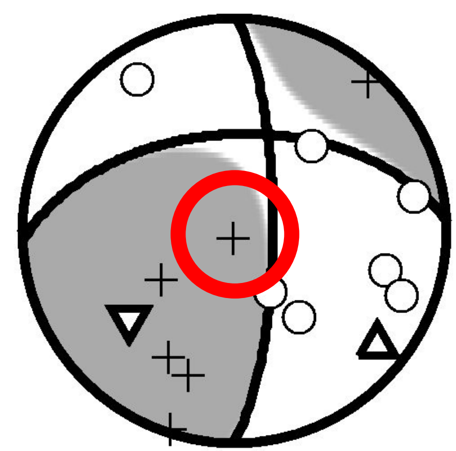


Strike-Slip plus

Normal Comp.
(Phases 1-7)



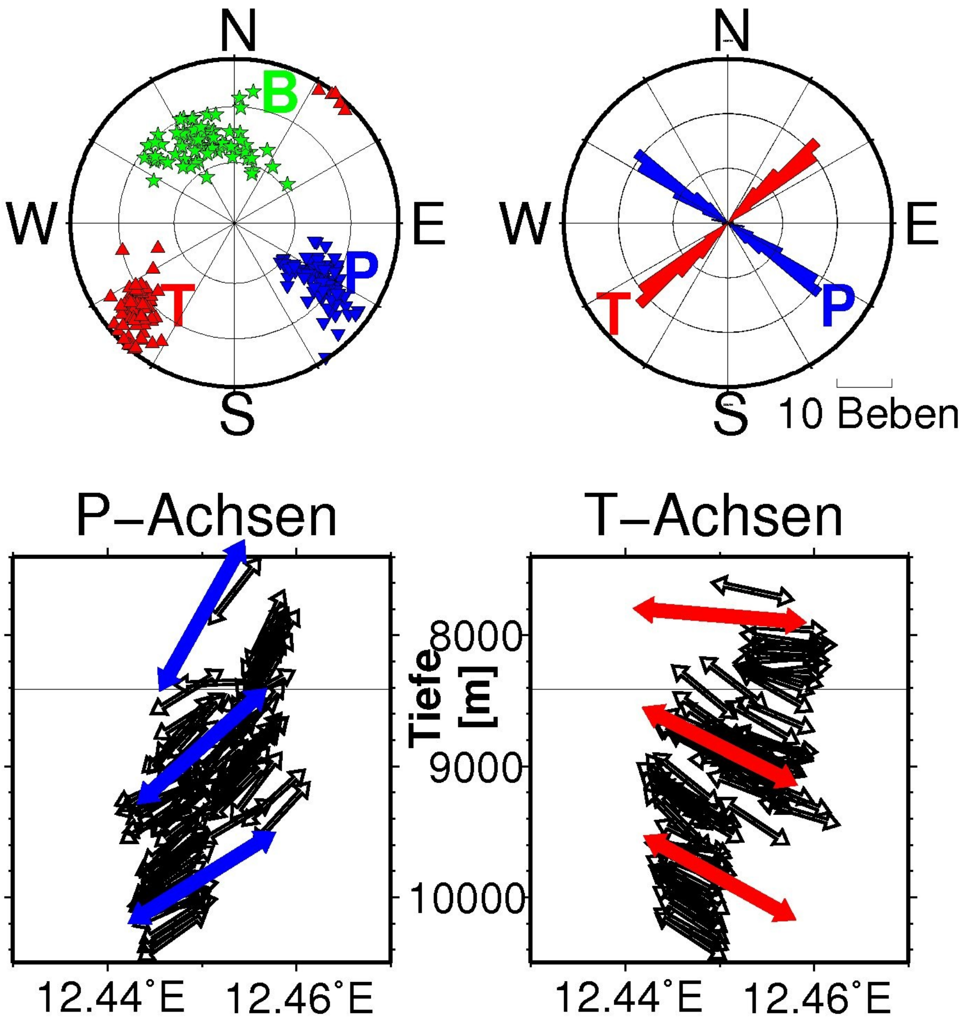
Reverse Comp
(Phases 1-4)



NKC

August – December 2000: P-, B-, T-axes

(Roessler, 2006)



P-Axes:

depth	strike	plunge
< 8,4 km	130°	50°
- 9,4 km	120°	39°
> 9,4 km	126°	26°

T-Axes:

depth	strike	plunge
< 8,4 km	226°	8°
- 9,4 km	228°	21°
> 9,4 km	228°	23°

Summary

- Stress field in Germany is dominated by NNW-SSE direction of maxmimum compression
- stress field due to Alpine orogenesis
- extension (Lower Rhine Graben) along pre-existing faults