INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4.SMR/942-23

Third Workshop on 3D Modelling of Seismic Waves Generation Propagation and their Inversion

4 - 15 November 1996

Seismic Risk in Intraplate Areas

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Seismotectonics

H. Bungum

NORSAR, Norway

Seismic Risk in Intraplate Areas

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by

Hilmar Bungum

NORSAR, Norway

Plate Margin vs. Intraplate

NORSAR

Characteristics	Plate margin Earthquakes	Intra Plate Earthquakes
Max Magnitude	~8.5	~7.5
Stress Drop	~3 MPa	~10 MPa
Recurrence Rate	30-200 yrs	100-10000 yrs
Slip Rate	>10 mm/yr	0.1-10 mm/yr

'Stable Continental Interiors'

(after Johnston)

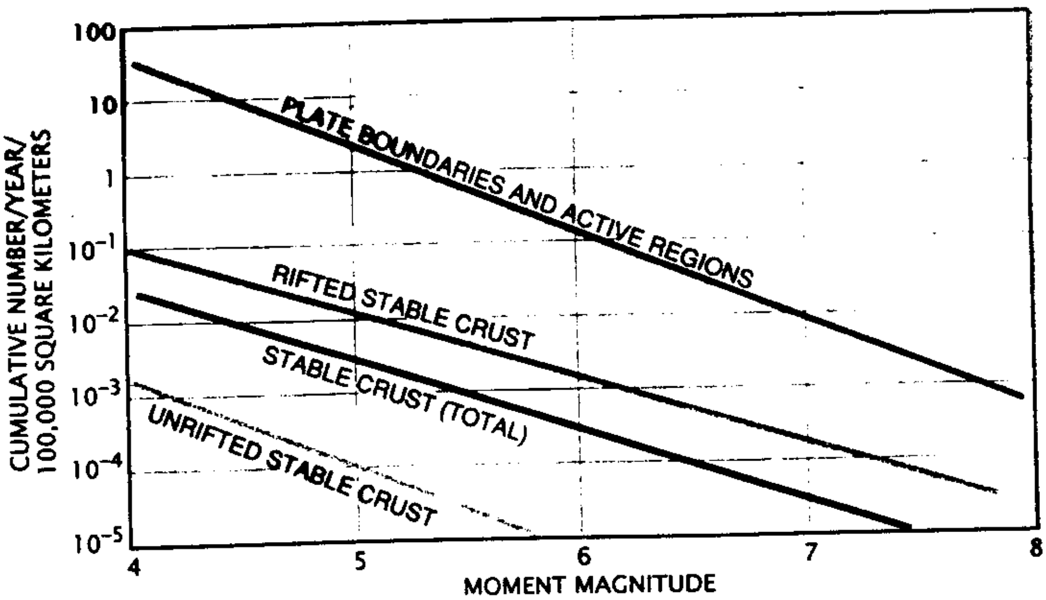
(1)	Paleozoic or older	(> 200 Ma)
	Low heat flow	(< 2 HFU)
	Low attenuation	(Q > 400-800)
	Low strain rate	(10^{-10}-10^{-12} yr^{-1})

(2) 72% of continental crust
30% of all crust
< 0.4% of seismic moments

(3) Largest quakes: M_w ~ 8.0
(At plate margins: M_w ~ 9.4)

(4) Quakes with M_S > 6.9 all in extended crust
(all except one at passive margins)

(5) Non-extentional environments: M_S < 6.9
(Australia)



SEISMIC ACTIVITY at plate boundaries and the associated active regions is compared with activity in several kinds of stable crust by a frequency-magnitude diagram. Earthquakes of all sizes are several hundred times more common at plate boundaries than they are in stable regions. Within stable crust, earthquakes take place more often in rifted areas; the correlation is the strongest for the largest events.

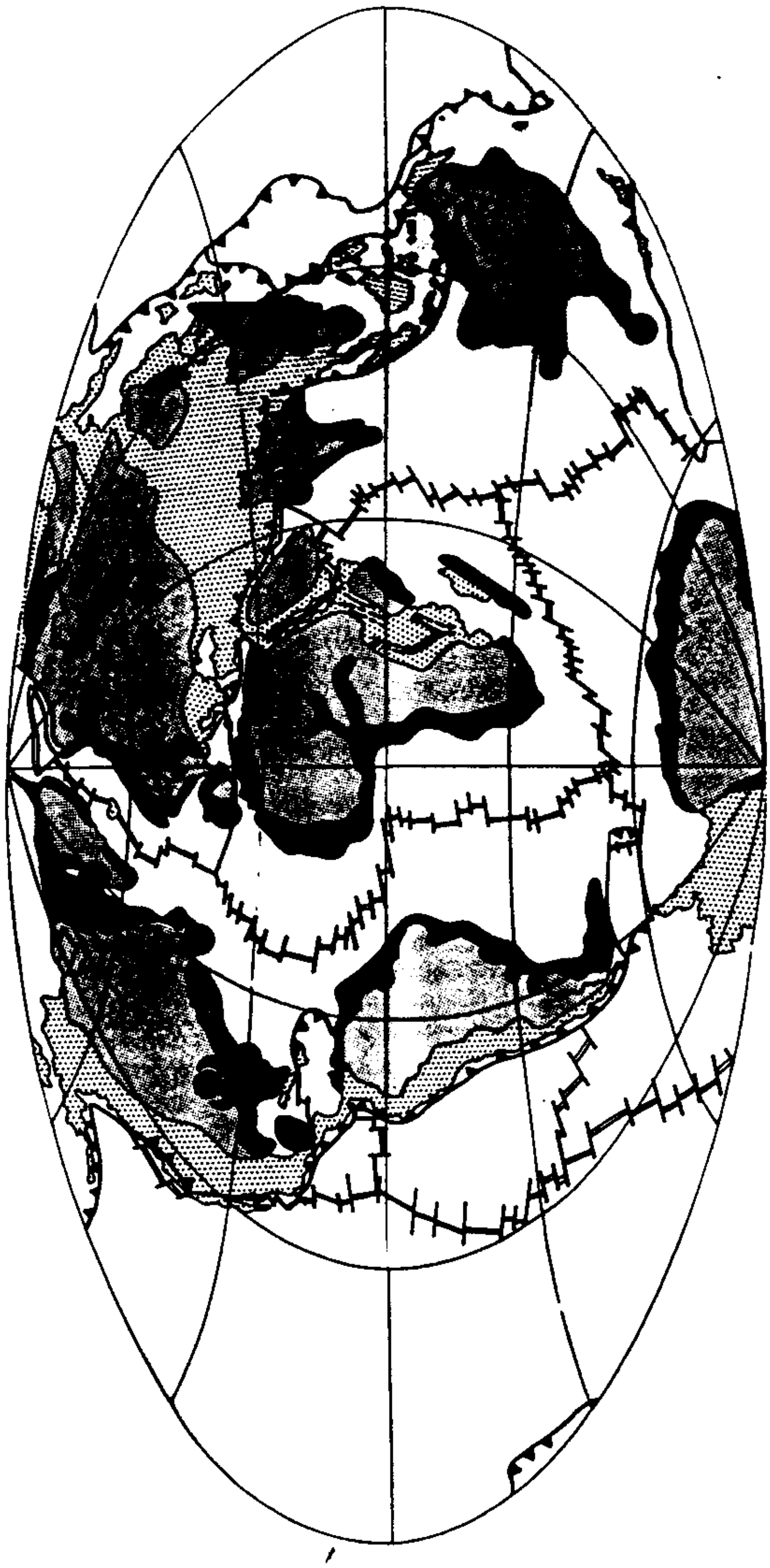
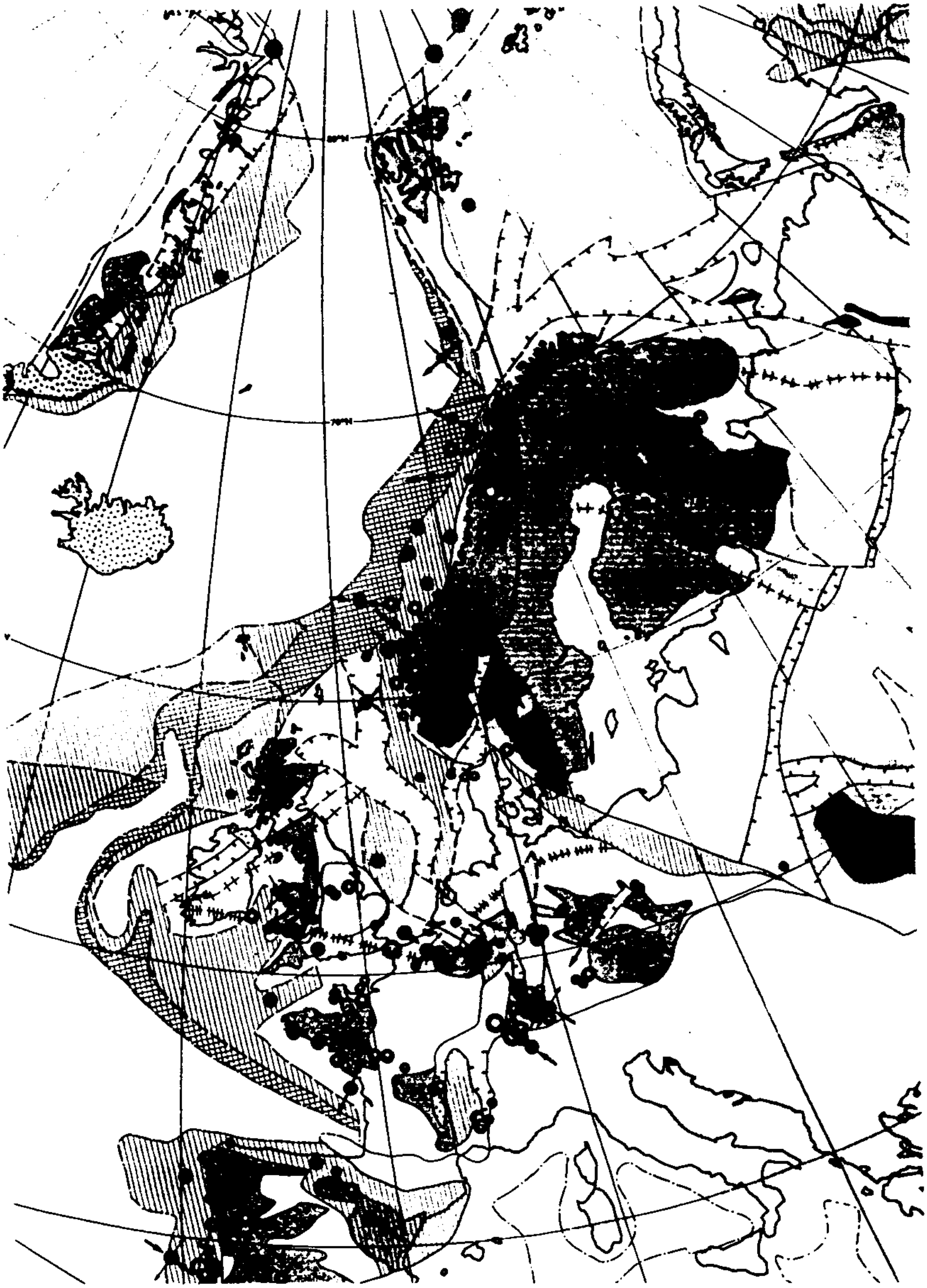


Figure 4-1
The stable continental regions of the Earth (light grey for non-extended, hachured for extended) in relation to plate boundaries and other portions of plate interiors (active intraplate, stippled; oceanic intraplate, white). The SCR earthquakes of $M \geq 7$ are included (filled circles).



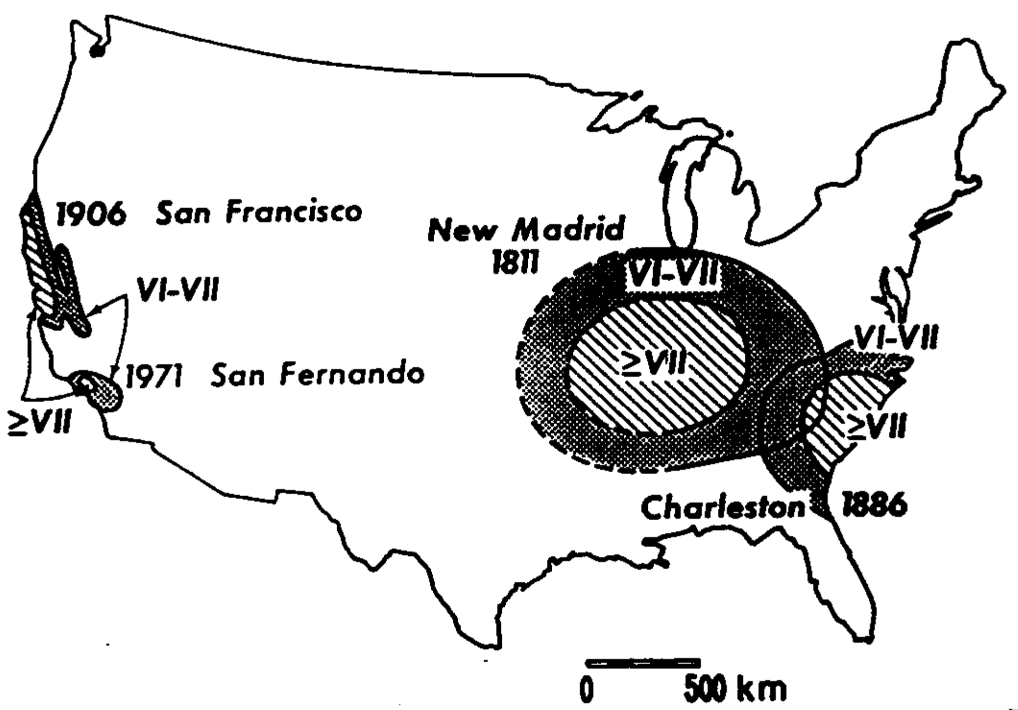
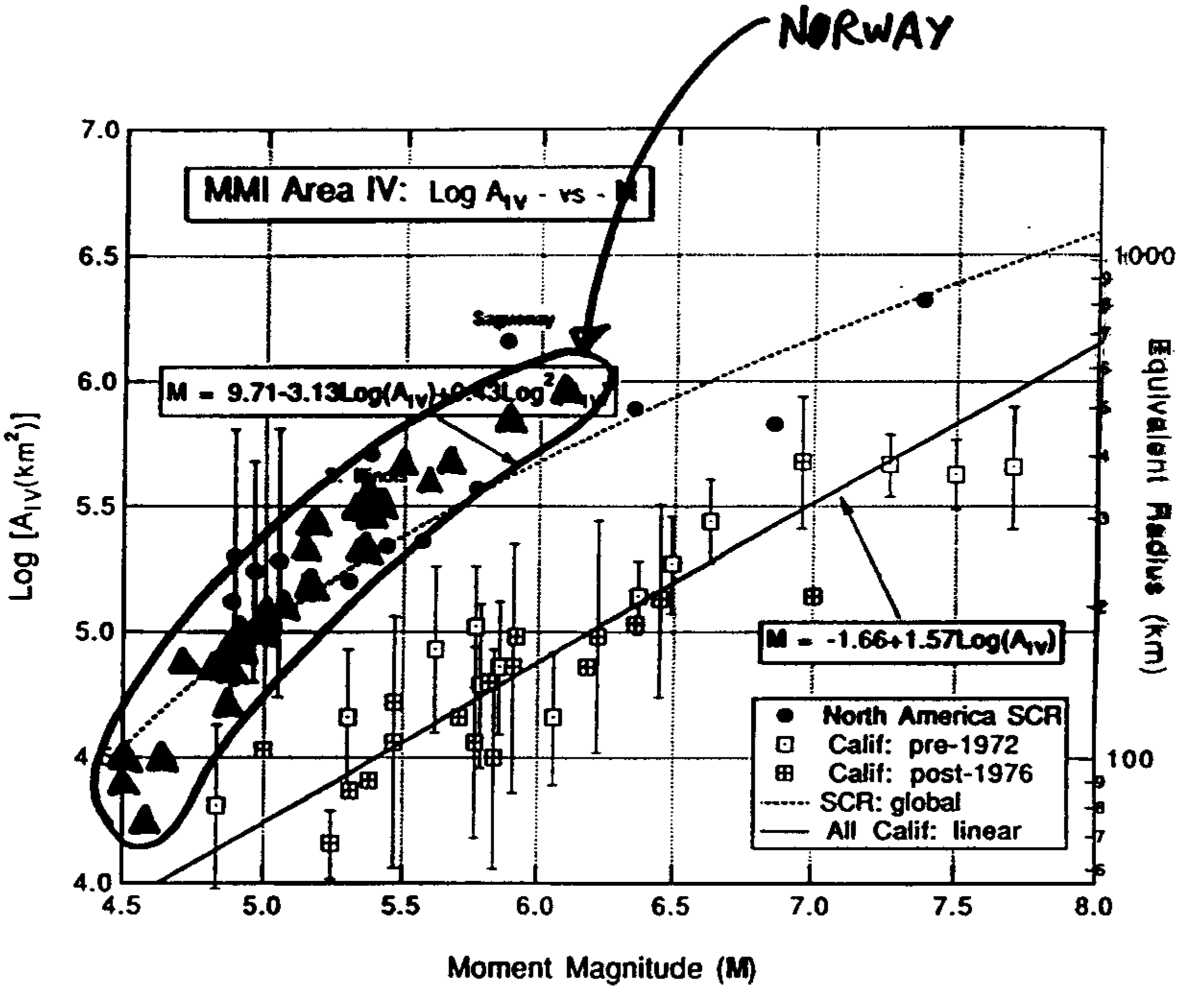


Fig. 5.2. Felt areas (intensities VII or greater) for the 1811 M_w 7.5 Missouri, the 1886 M_w 6.8 Charleston, the 1906 M_w 7.7 San Francisco and the 1971 M_w 6.6 San Fernando earthquakes. (From Schnell and Herd, 1984).



NORWAY
MMI Area IV: Log A1V - vs - M
Saguenay
M = 9.71-3.13Log(A1V)+0.43Log²(A1V)
M = -1.66+1.57Log(A1V)
North America SCR
Calif: pre-1972
Calif: post-1976
SCR: global
All Calif: linear
Log [A1V(km²)]
Equivalent Radius (km)
Moment Magnitude (M)
7.0
6.5
6.0
5.5
5.0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
1000
100

Stress Generating Mechanisms

Stress Field	Lateral Endurance	Stress Generating Mechanism
1. order	> 1000 km	**Plate Tectonic Forces** Ridge Push Slab Pull Basal Drag
2. order	100-1000 km	**Large Scale Density Inhomogeneities** COB **Flexural Stresses** Deglaciation Sediment Loading **Major Topographic Loads**
3. order	< 100 km	**Topography** Fjords Mountain Ranges **Geological Features** Faults Hard and Soft Inclusions

POSSIBLE STRESS SOURCES AT PASSIVE MARGINS

TYPE	MAGNITUDE	DIRECTION	SPATIAL VARIATION	DEPTH VARIATION	LOCATION
Ridge push	10 MPa	often ridge-normal	compression	monotonic	all margins
Continental margin	10 MPa	essentially margin - normal	continent-extension; ocean-compression	monotonic	all margins
Deglaciation flexure	10 MPa	essentially margin - normal	continent-extension; ocean-compression	reverses	deglaciated margins
Sediment flexure	100 MPa	essentially margin - normal	continent-extension; ocean-compression	reverses	all margins

From Stein et al., 1989

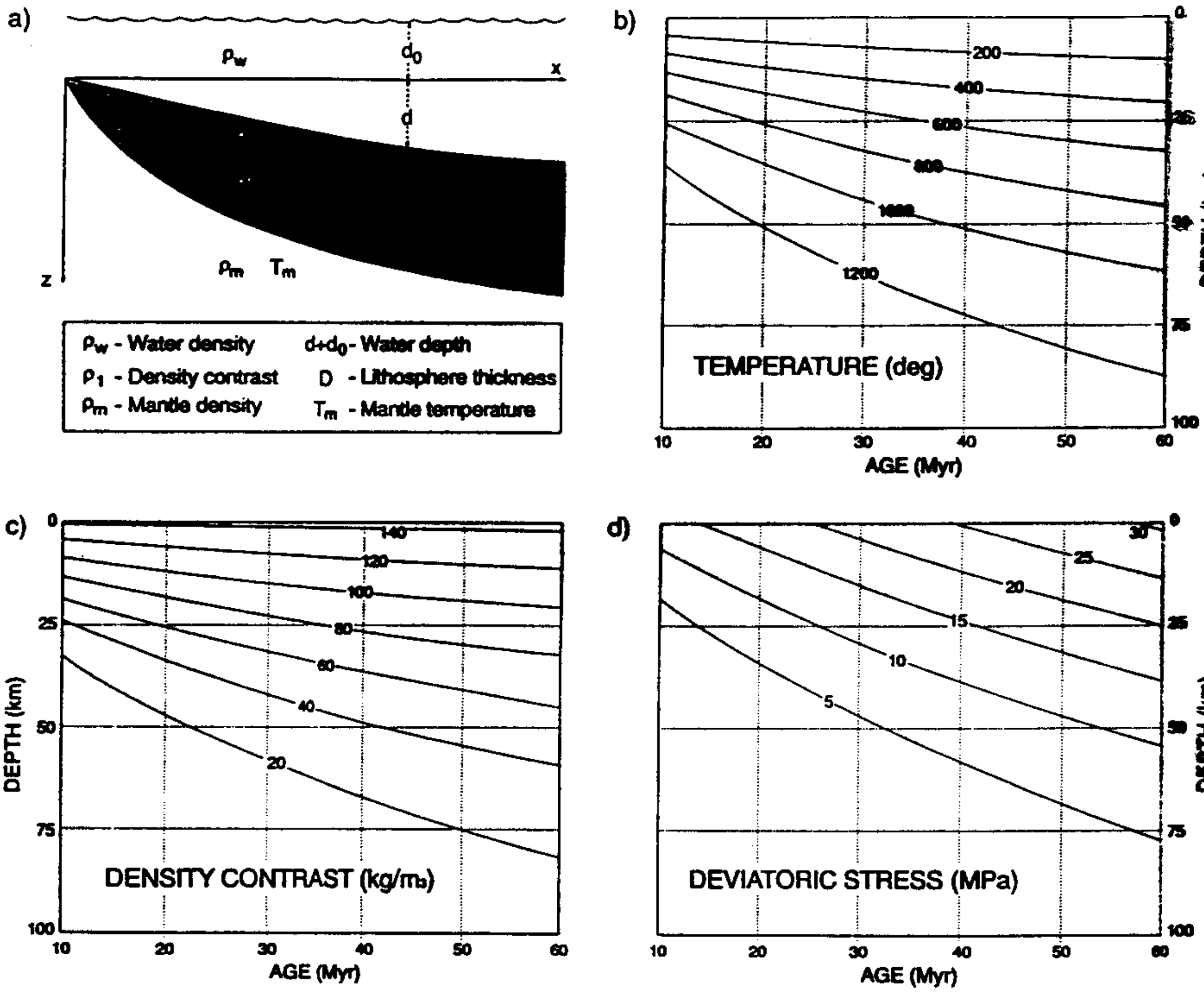
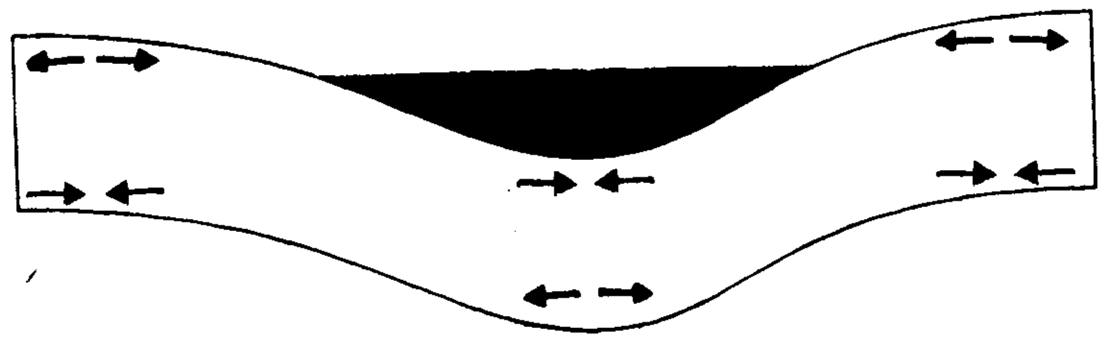

a)
ρw
d0
x
d
z
ρm Tm
ρw - Water density
d+d0 - Water depth
ρ1 - Density contrast
D - Lithosphere thickness
ρm - Mantle density
Tm - Mantle temperature
b)
TEMPERATURE (deg)
200
400
600
800
1000
1200
AGE (Myr)
DEPTH (km)
c)
DENSITY CONTRAST (kg/m3)
140
120
100
80
60
40
20
DEPTH (km)
AGE (Myr)
d)
DEVIATORIC STRESS (MPa)
30
25
20
15
10
5
DEPTH (km)
AGE (Myr)

Figure 3

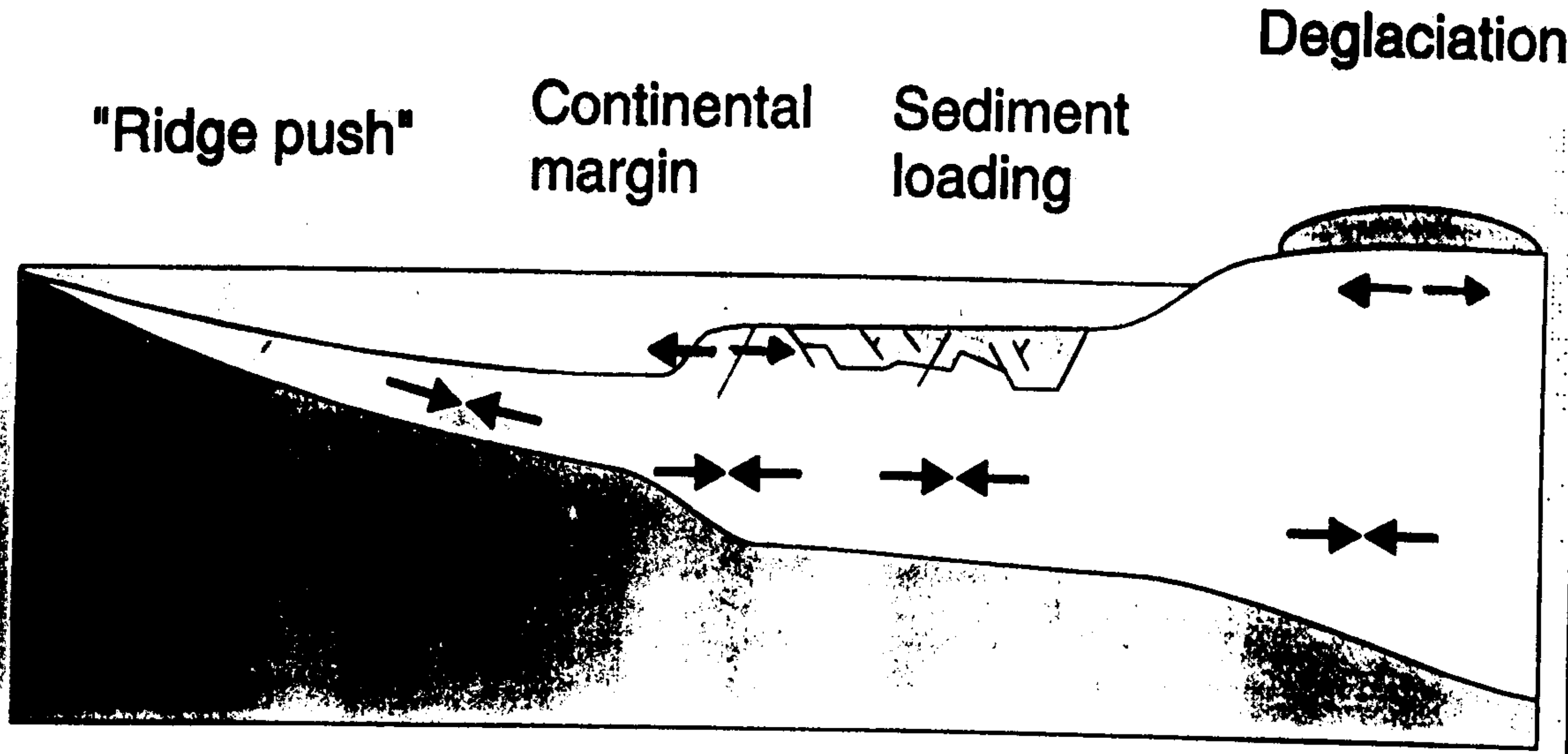
SEDIMENT LOADING

- **Deflection of the lithosphere due to a sediment load cause flexural stresses.**

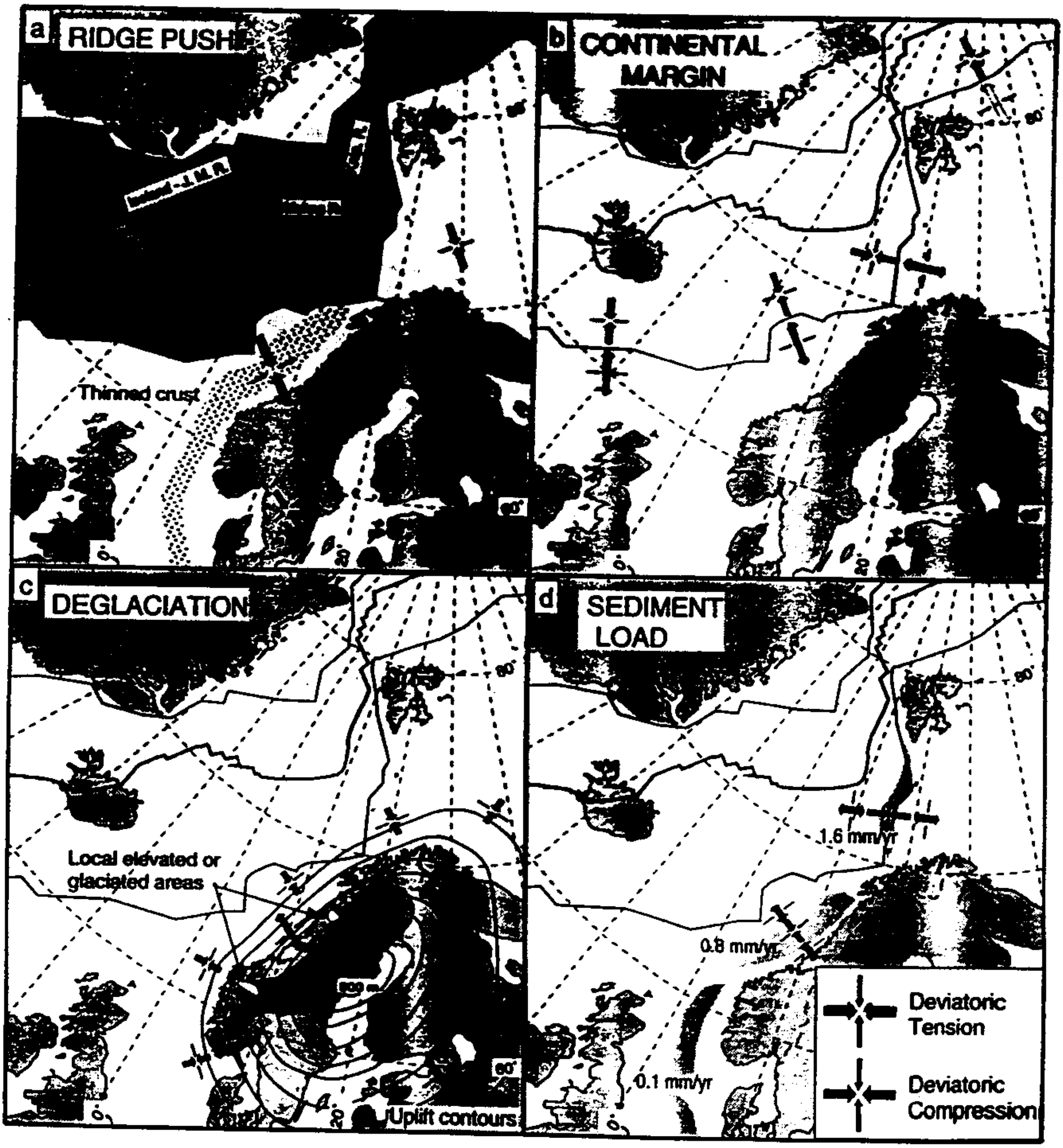


- **The flexural stresses is dependent on lithosphere rheology, basin dimensions and loading history.**
  - **Elastic plate behaviour yield high flexural stresses**
  - **Visco-elastic plate behaviour yield lower flexural stresses**
  - **Brittle-ductile plate behaviour yield intermediate flexural stresses**

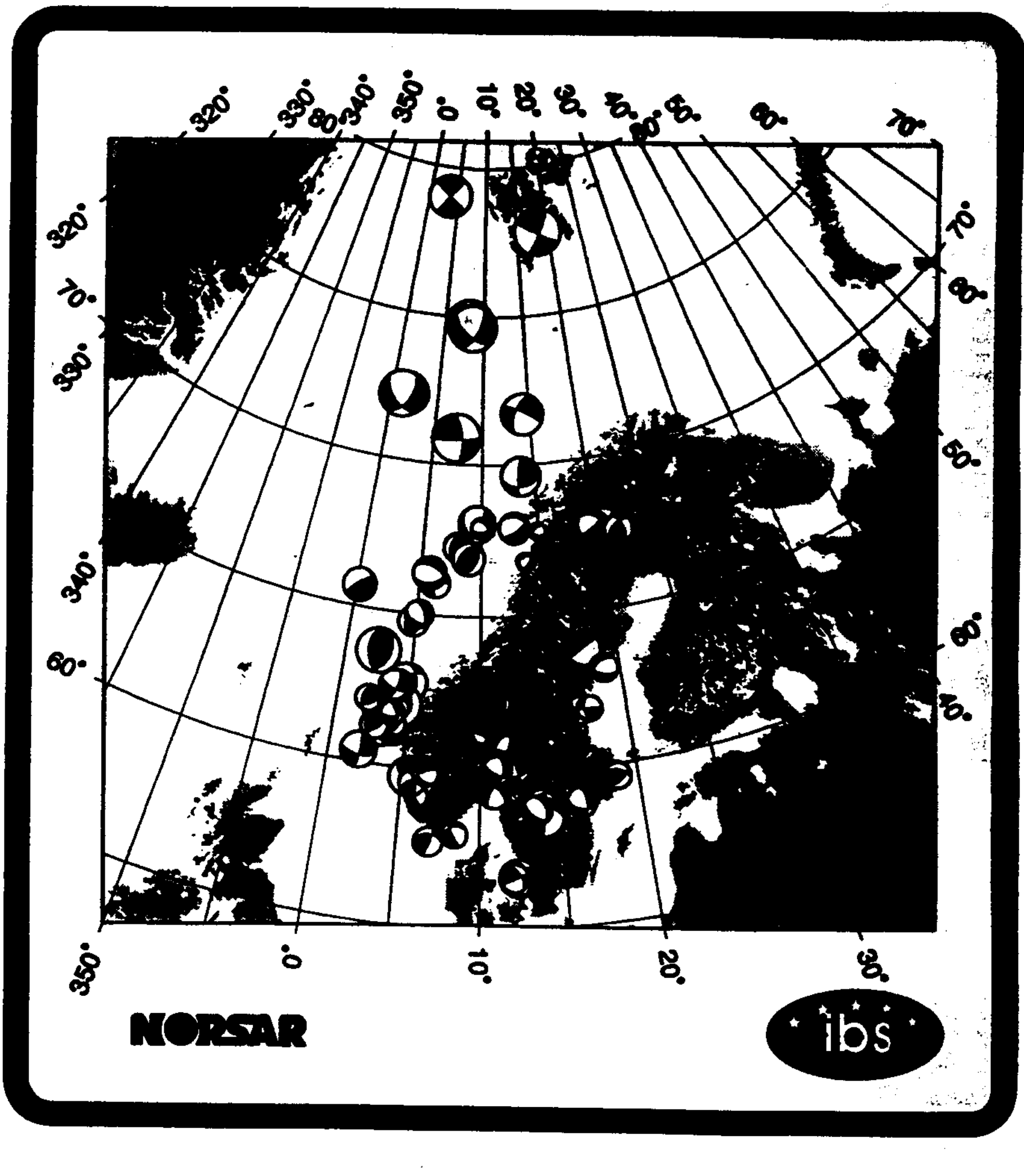
Mechanisms generating tectonic stress



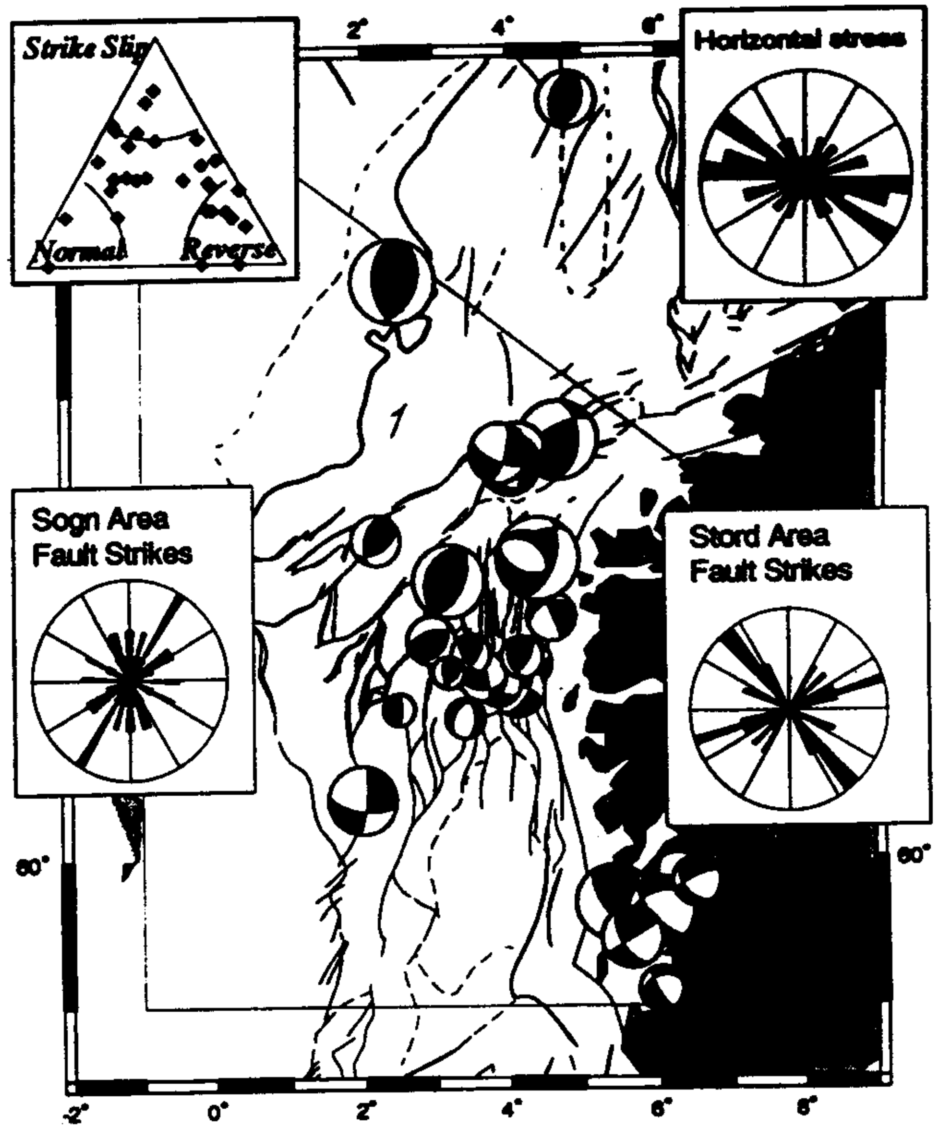
ibs



REGIONAL STRESS GENERATING MECHANISMS ACTING IN THE NORWEGIAN AREA

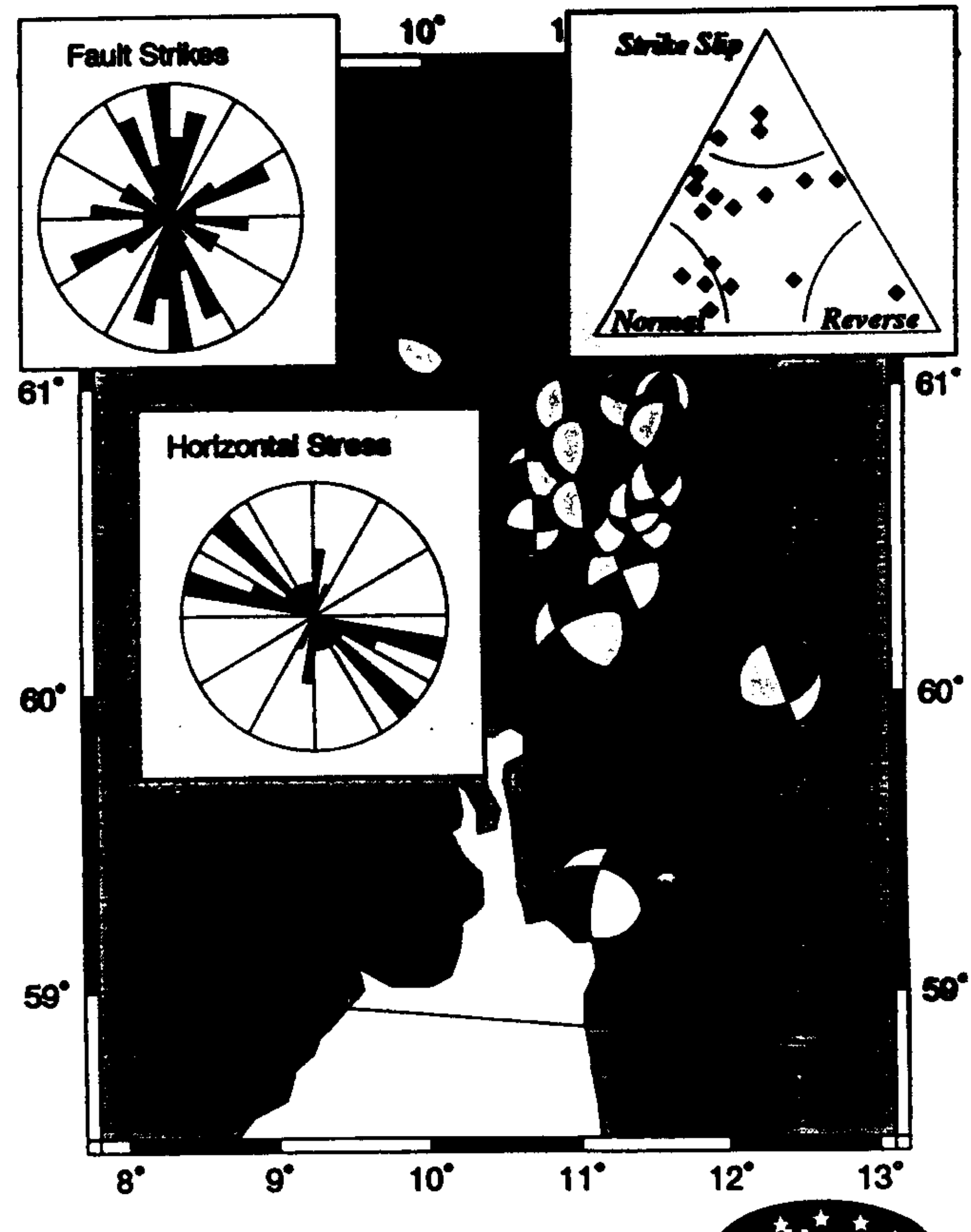


320°
330°
340°
350°
0°
10°
20°
30°
40°
50°
60°
70°
80°
350°
0°
10°
20°
30°
NORSAR
ibs


Strike Slip
Normal
Reverse
Horizontal stress
Sogn Area
Fault Strikes
Stord Area
Fault Strikes
2°
4°
6°
60°
60°
-2°
0°
2°
4°
6°
8°

NORSAR

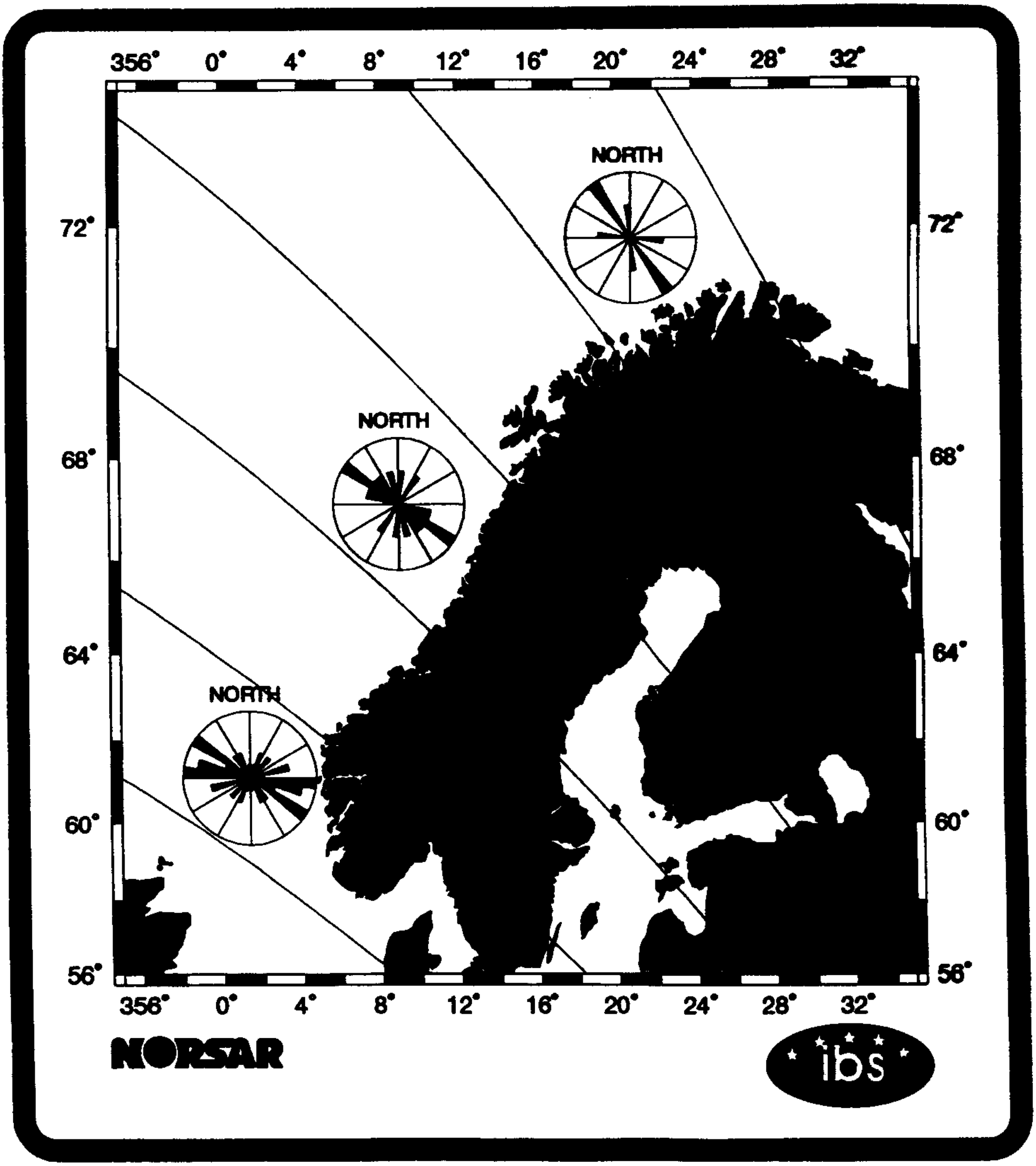
ibs

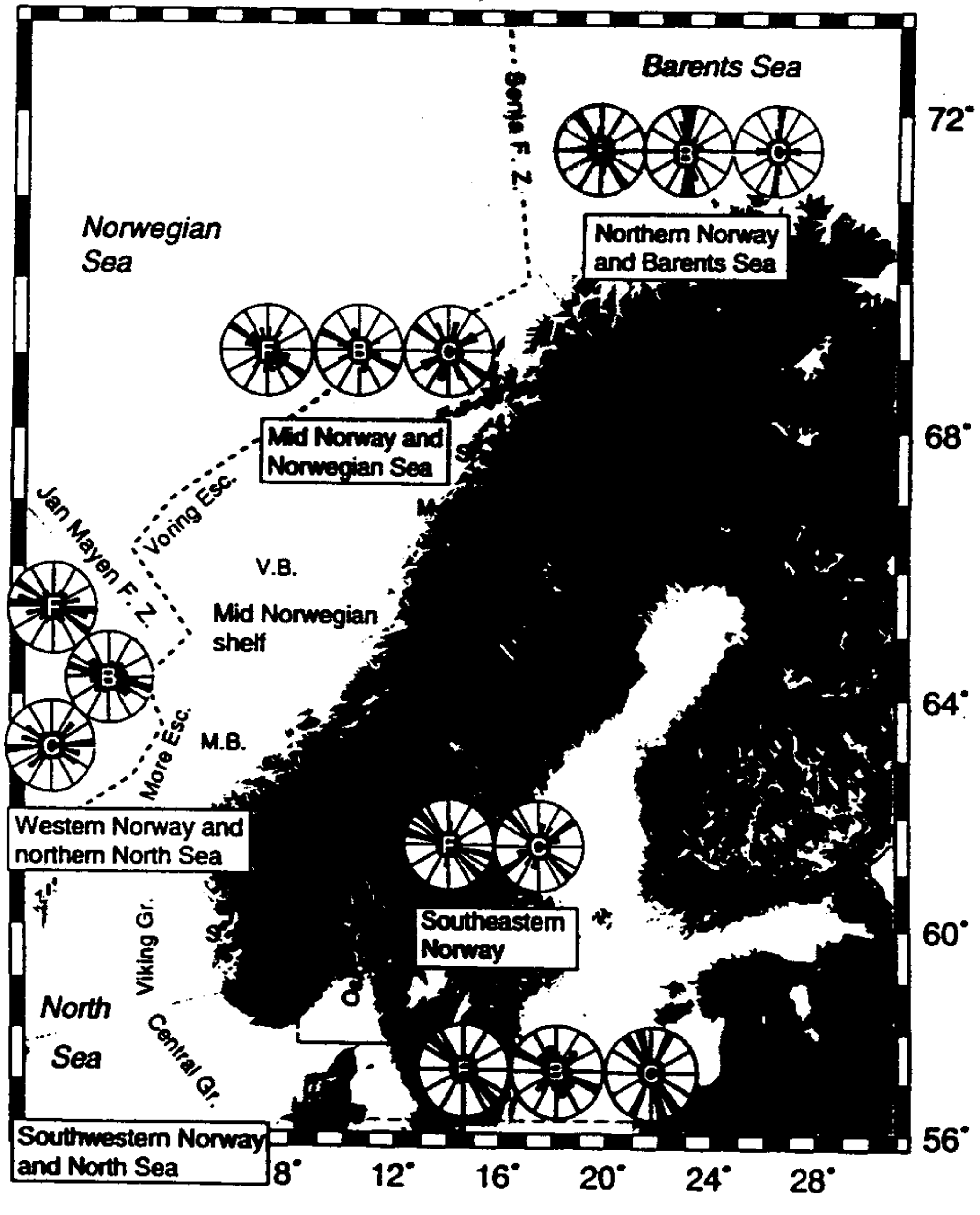


Fault Strikes
Strike Slip
Normal
Reverse
Horizontal Stress
10°
61°
60°
59°
8°
9°
10°
11°
12°
13°

NORSAR

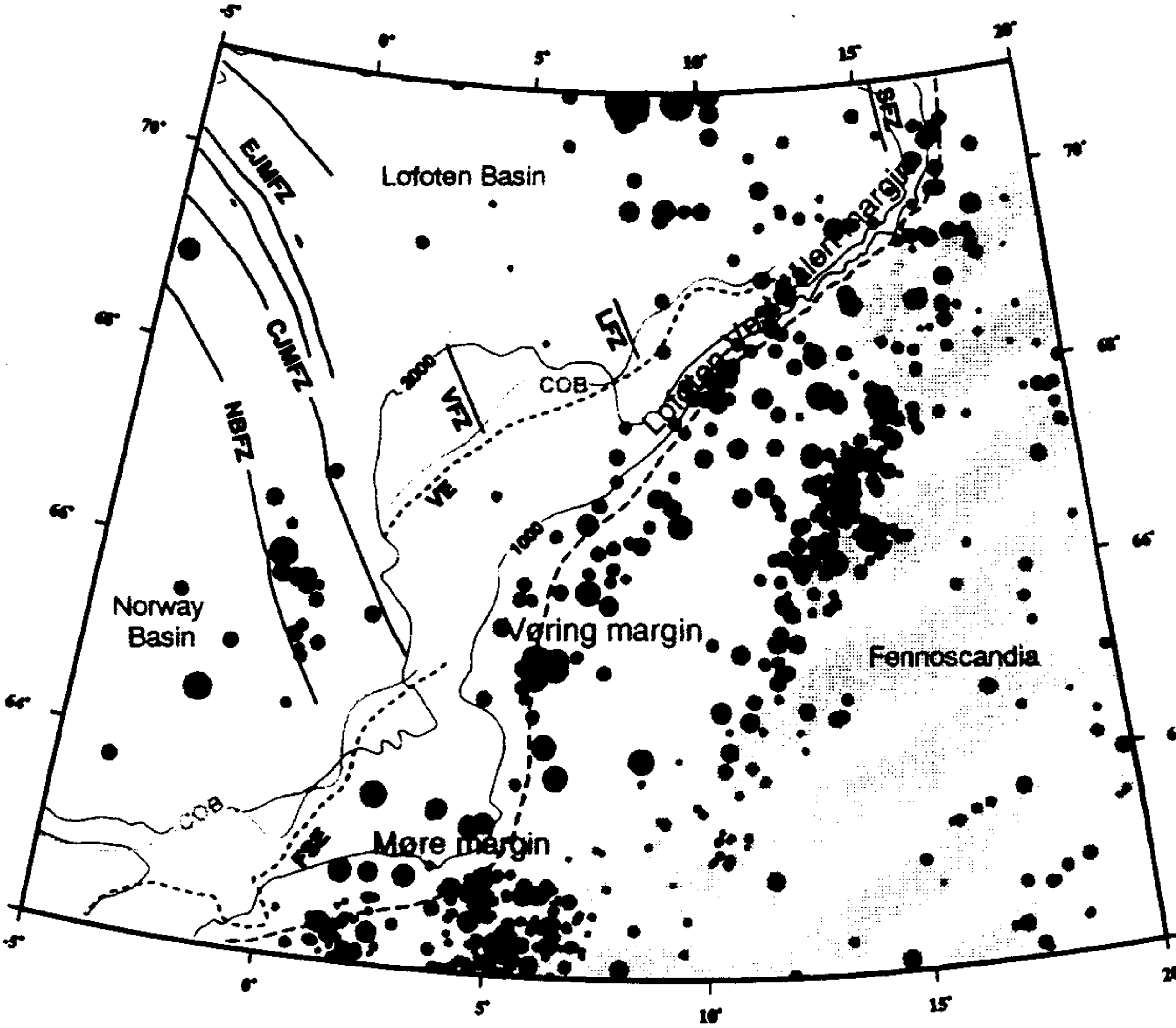
ibs


356° 0° 4° 8° 12° 16° 20° 24° 28° 32°
72°
68°
64°
60°
56°
NORTH
NORTH
NORTH
NORSAR
ibs


Barents Sea
Senja F. Z.
Norwegian Sea
Northern Norway and Barents Sea
Mid Norway and Norwegian Sea
Jan Mayen F. Z.
Voring Esc.
V.B.
Mid Norwegian shelf
More Esc.
M.B.
Western Norway and northern North Sea
Southeastern Norway
Viking Gr.
North Sea
Central Gr.
Southwestern Norway and North Sea
8°
12°
16°
20°
24°
28°
72°
68°
64°
60°
56°

Regional Seismicity

NORSAR



Magnitudes: ● = 6 ● = 5 ● = 4 • = 3 · = 2

- - - - - - - **Shelf edge**

Approximate continent-oceanic boundary (COB)

- - - - - - - - - - **Vøring and Faroe-Shetland Escarpment**

——————— **Bathymetry, 1000 m**

Structural Elements

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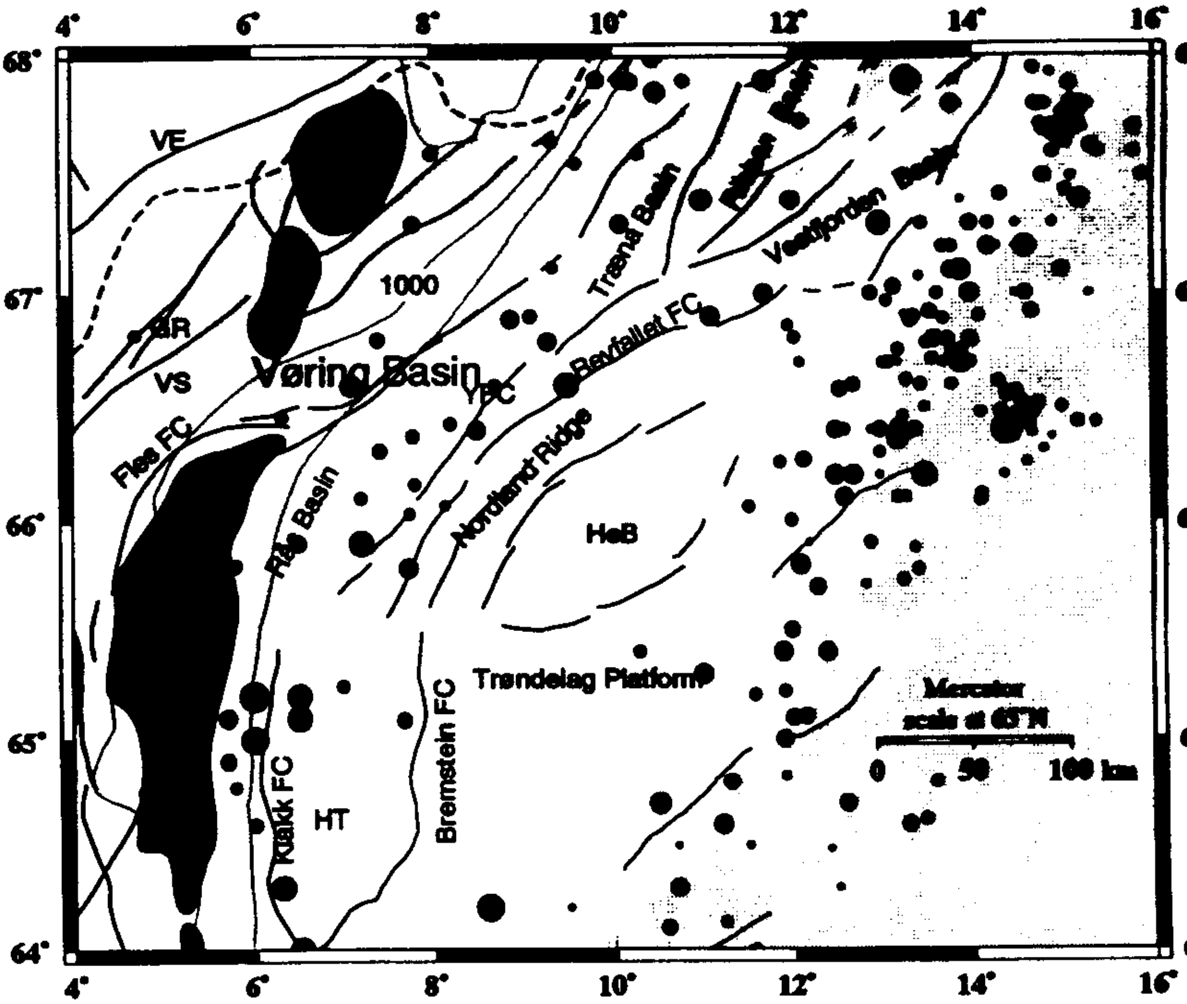
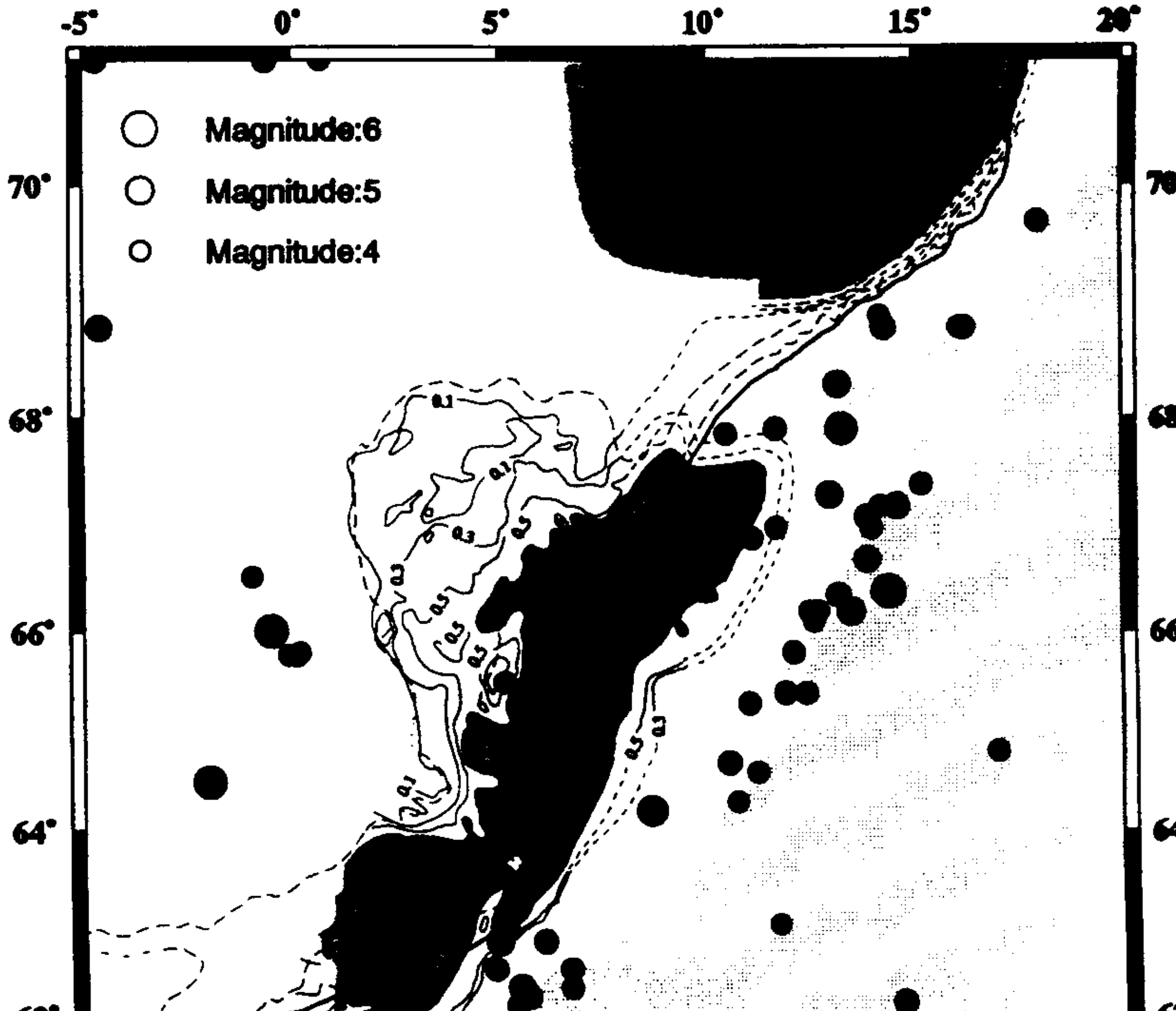


Post Miocene Sediments



Post Glacial Rebound

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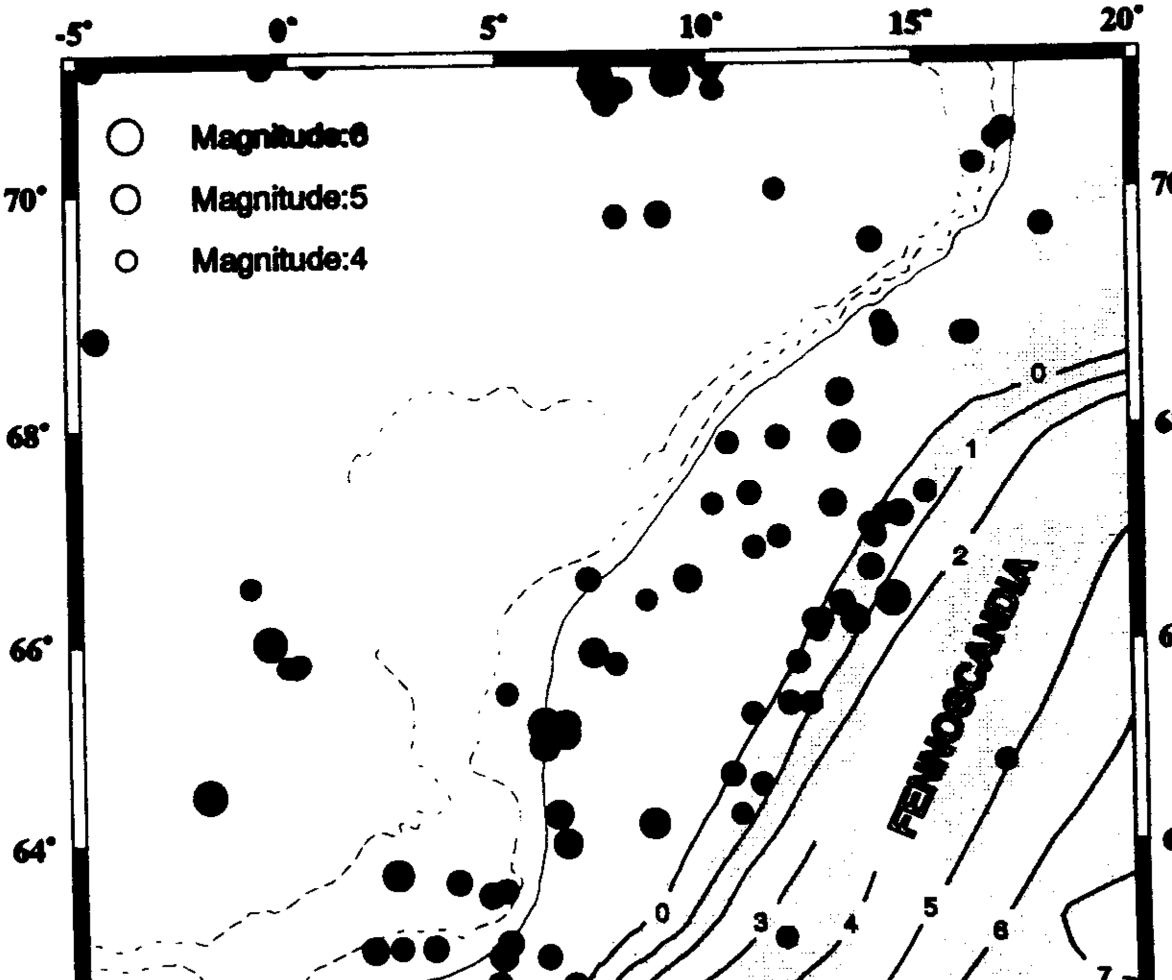

Mechanisms - Basin Areas

Stress Generating / Modifying Mechanism Basin areas				
Factor	**Province**			
	Eastern Vøring Basin	**Western Vøring Basin**	**Eastern Møre Basin**	**Western Møre Basin**
Quakes	yes	no	yes	yes
Faults	yes	yes	yes	no
P-M Loads	yes	no	yes	yes
COB	no	yes	no	yes
Topo	yes	no	yes	no
Thin Crust	yes	yes	yes	yes

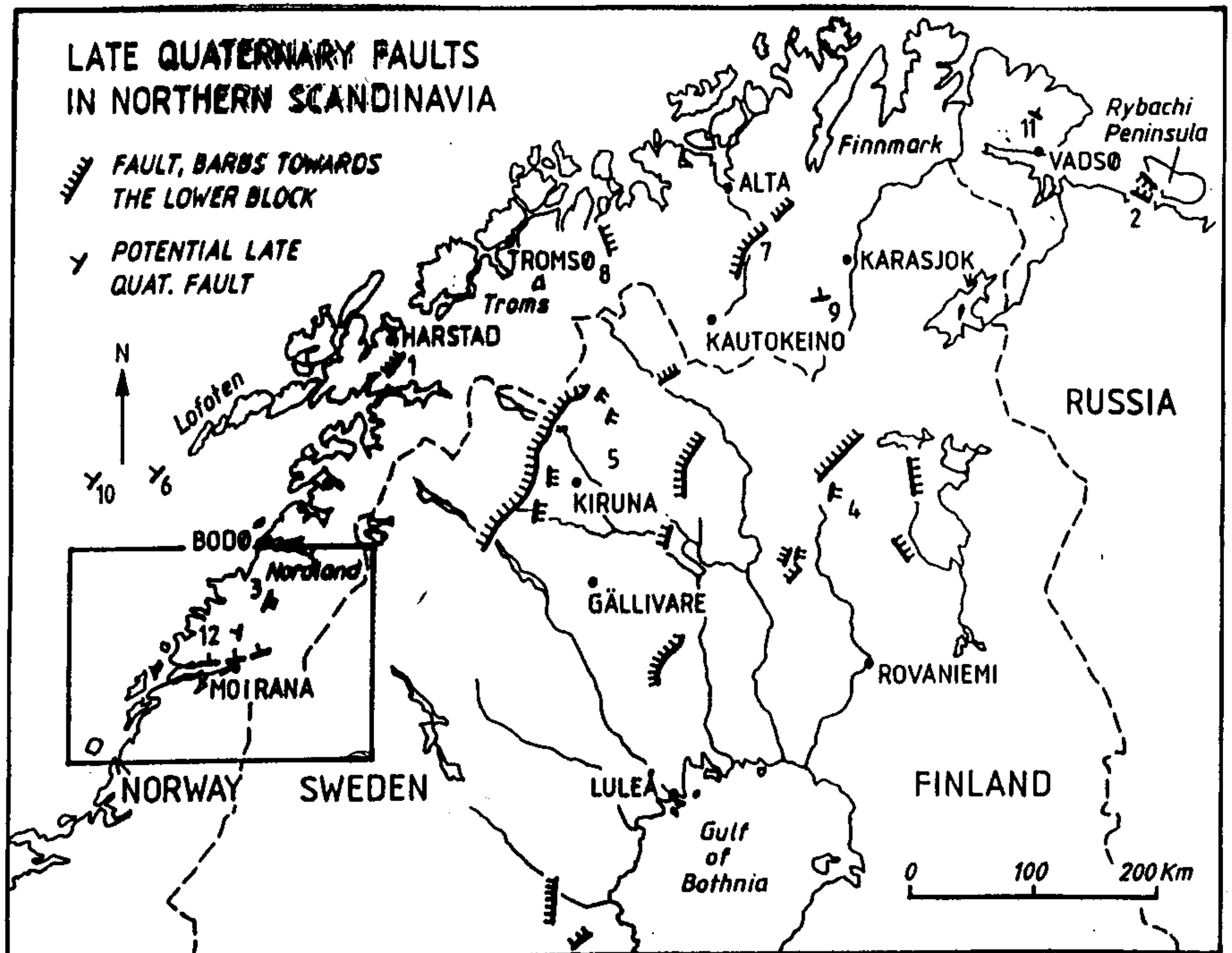

Fig. 1. ***Reported Late Quaternary faults in northern Fennoscandia from 1, Grønlie (1922), Vogt (1923); 2, Tanner (1930); 3, Grønlie (1939); 4, Kujansuu (1964); 5, Lundquist & Lagerbäck (1976), Lagerbäck (1979); 6, Rokoengen & Sættem (1983); 7, Olesen (1988); 8, Tolgensbakk & Sollid (1988); 9, Olsen (1989); 10, Mokhtari (1991); 11, Olesen et al. (1992b) and 12, present study. Faults 6,10,11 and 12 are classified as potential Late Quaternary faults since they may also be attributed to other causes (see criteria for classifying postglacial faults in Fennoscandia by Muir Wood (1993)). The present study area is shown by the frame.***

Fault Name		Length (km)	Max. displ. (m)	Moment (Nm)	Magnitude (M_w)
A	Pärve	165	13	1.4×10^{21}	8.1
B	Stuoragurra	80	7	3.7×10^{20}	7.7
C	Lainio-Suijavaara	55	30	1.0×10^{21}	8.0
D	Suasselka	48	5	1.3×10^{20}	7.4
E	Lansjärv	50	22	6.1×10^{20}	7.9

Table 1. Faults within the Lapland post-glacial fault province (see Fig. 1 for geographical locations). Fault lengths and displacements are from Muir Wood (1993), while seismic moments and magnitudes are calculated here.

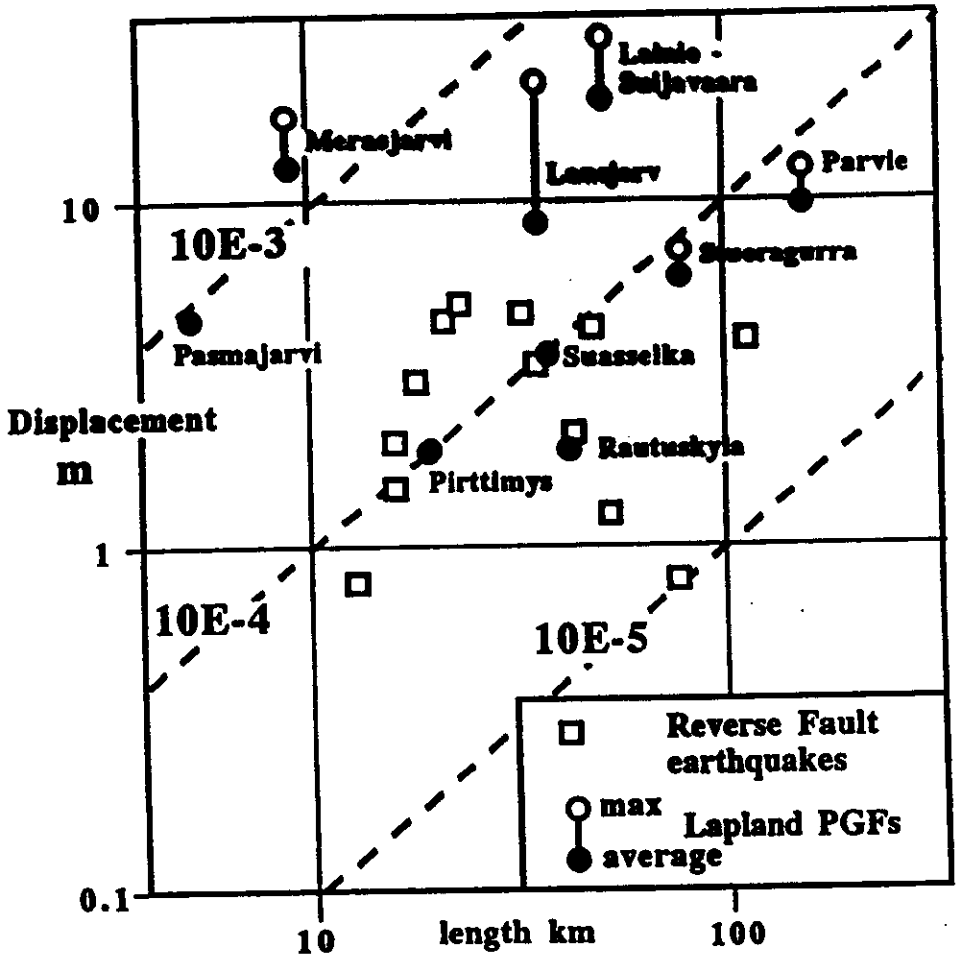

Figure 3-8: Log. fault length vs Log. displacement for Lapland post-glacial faults and other recent reverse fault scarps.