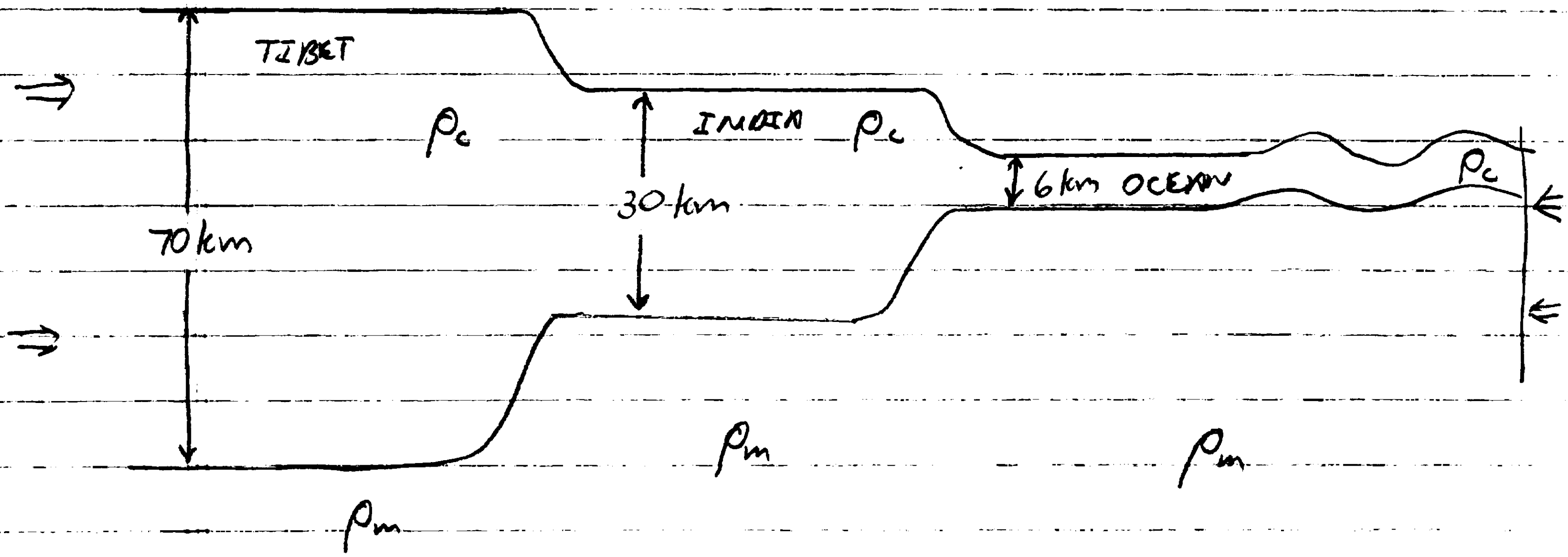
FORCE BALANCES IN THE LITHOSPHERE

(show topography and earthquakes and gravity for Indian plate)

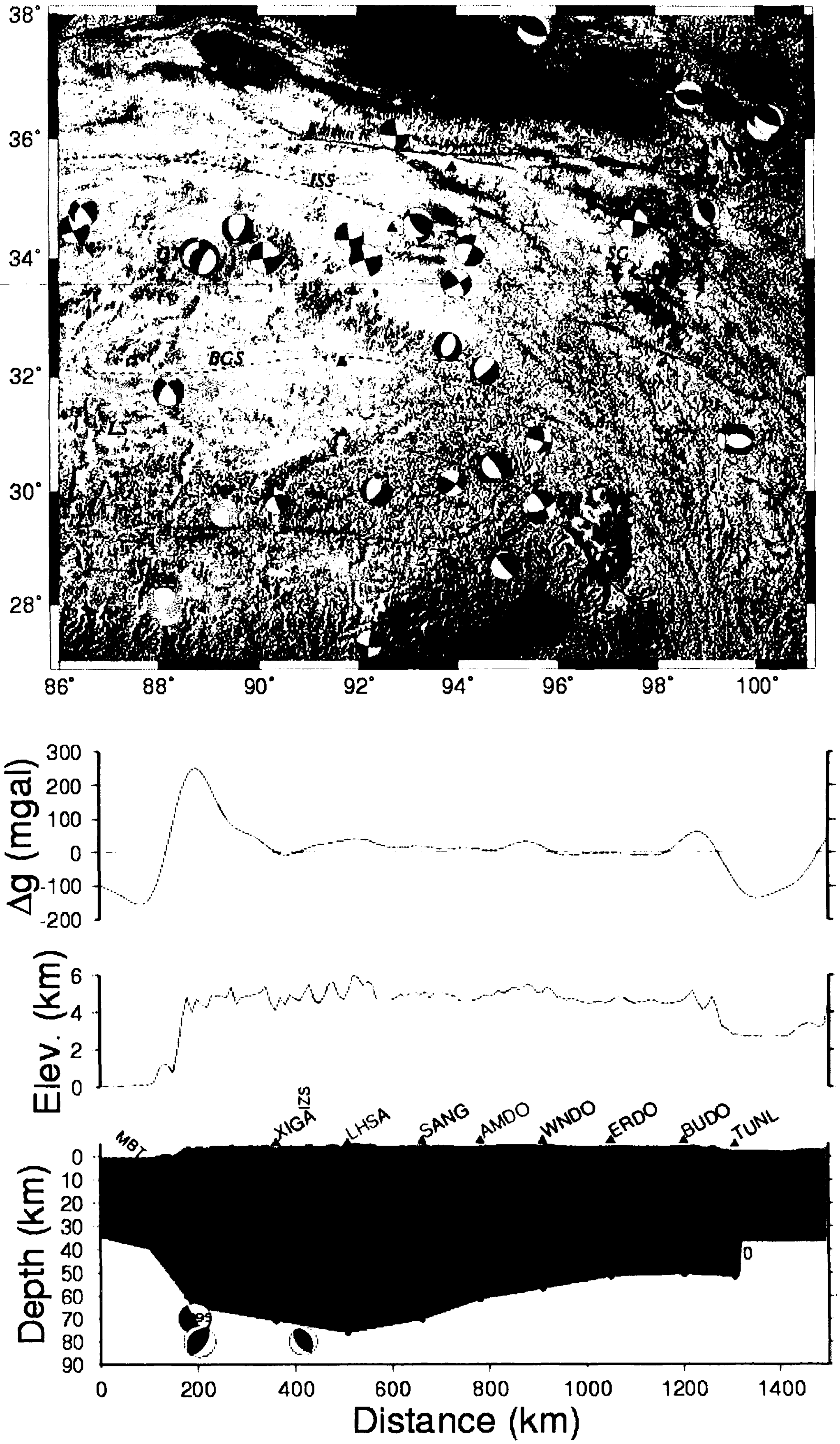
What limits the height of the plateau in Tibet?



What is the vertical force balance?

What is the horizontal force balance?

Why is continental lithosphere weaker than oceanic lithosphere?

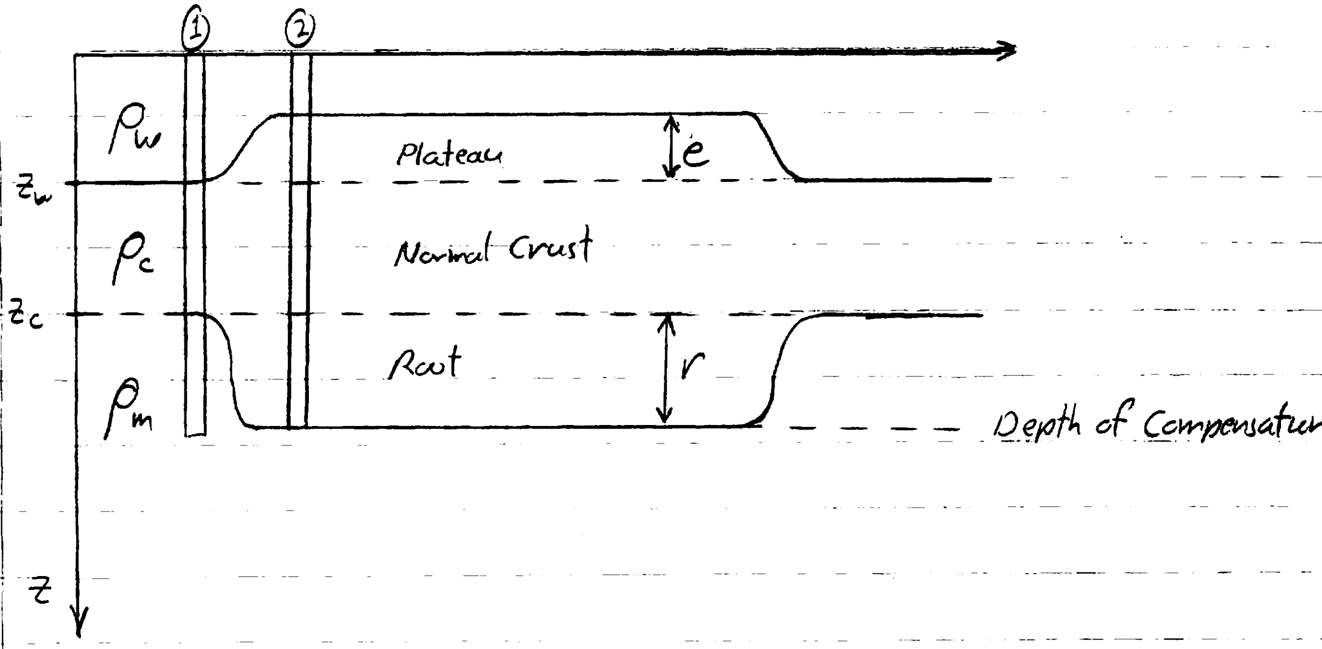


Lupei Zhu - web site
http://www.eas.slu.edu/People/LZhu/research/tibet/intro.html

AIRY COMPENSATION (Vertical Stress Balance)

Oceanic Plateau: (Nur and Ben-Avraham, 1982)
(Schubert and Sandwell, 1989 - on web site)

- There are many areas of the ocean floor that are shallower than predicted by the depth vs age relation. Areas that are generally flat on top with steeply dipping sides are called "oceanic plateaus". They are characterized by thicker than normal crust.



Isostasy - For any vertical column between the surface of the earth and the depth of compensation, the mass per area is a constant

The Airy Compensation model achieves isostatic balance by having a relatively low density root beneath elevated regions.

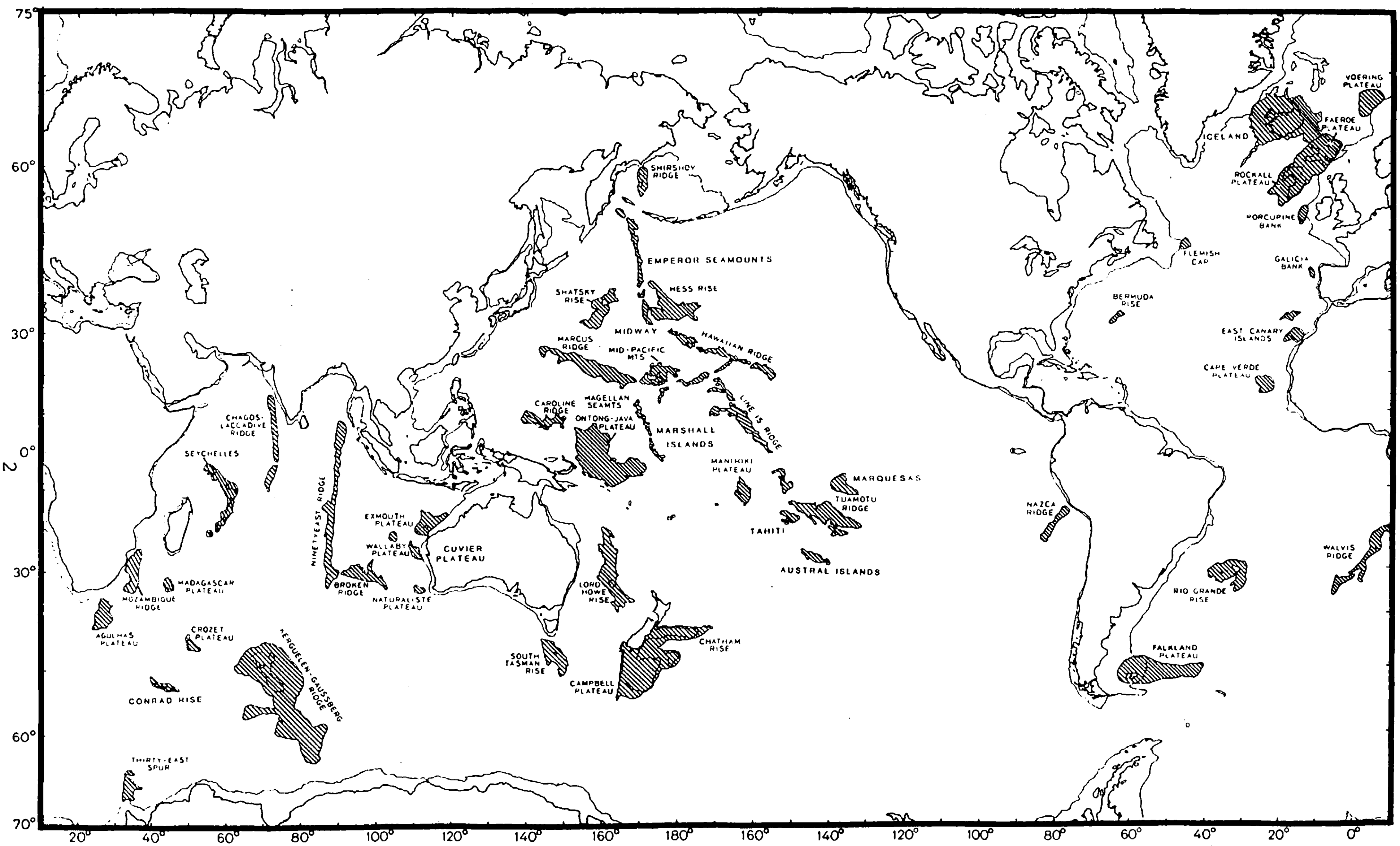


Fig. 1. Worldwide distribution of oceanic plateaus and swells that will be analyzed using geoid height and topography data (hachured; after Nur and Ben-Avraham, 1982).

(5)

To determine the thickness of the root r we compare the mass/area in the "standard" oceanic crustal column to the mass/area in the plateau column

Standard Crust = Plateau

$$\rho_w z_w + \rho_c (z_c - z_w) + \rho_m r = \rho_w (z_w - e) + \rho_c e + \rho_c (z_c - z_w) + \rho_c r$$

Subtract standard crust from both sizes:

$$0 = e(\rho_c - \rho_w) - r(\rho_m - \rho_c)$$

$$r = e \frac{(\rho_c - \rho_w)}{(\rho_m - \rho_c)}$$

$$h_t(e) = (z_c - z_w) + e\left[1 + \frac{(\rho_c - \rho_w)}{(\rho_m - \rho_c)}\right] \quad \text{(total crustal thickness)}$$

Example: Suppose normal oceanic crust has a thickness of 6 km and a density of 2800 kg/m³, what is the total crustal thickness for an oceanic plateau with a height of 2 km.

$$\frac{(\rho_c - \rho_w)}{(\rho_m - \rho_c)} = 3.54$$

$h_t = 15$ km $\qquad e = 2$ km

VIEWGRAPH

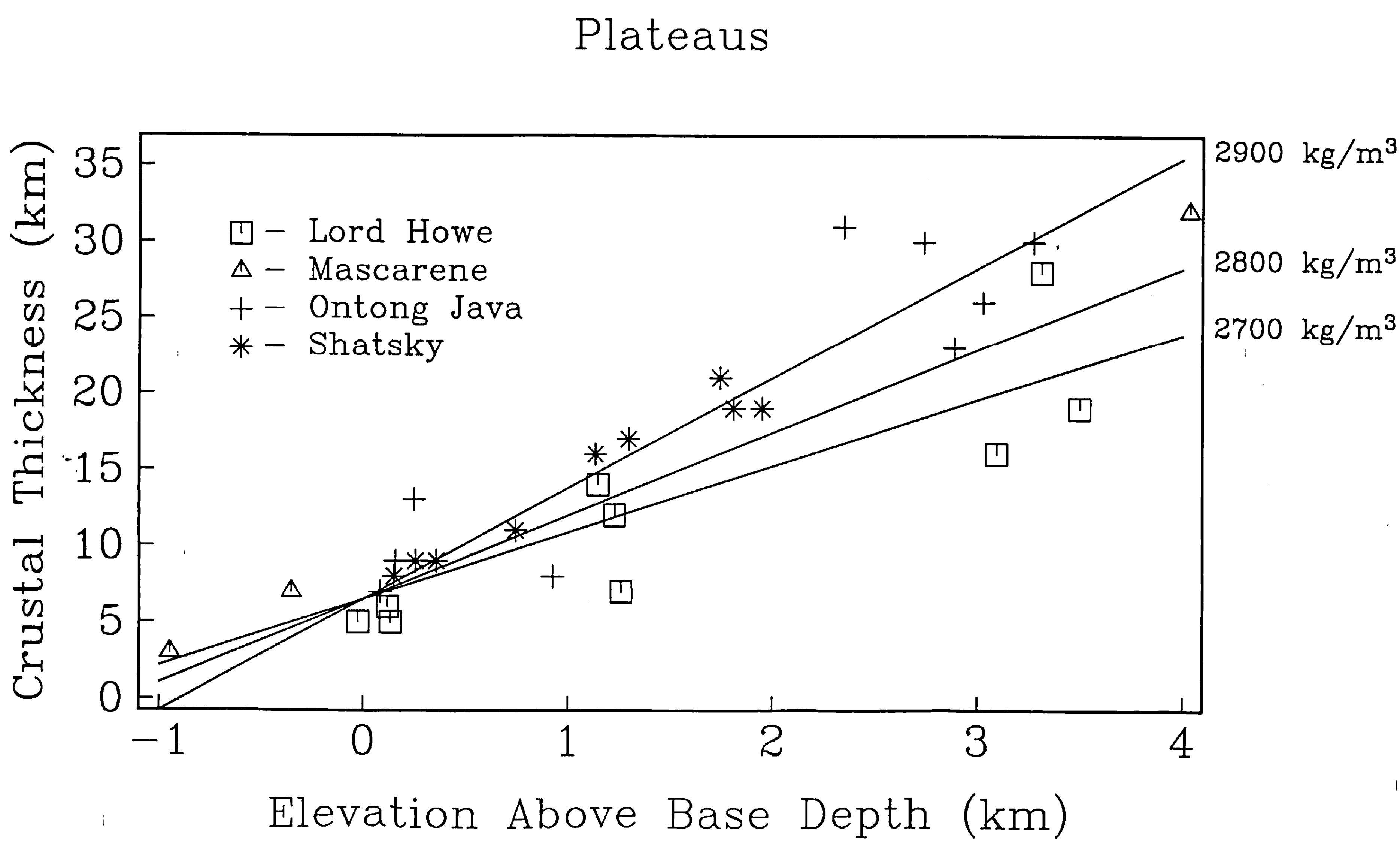

Plateaus
Crustal Thickness (km)
Elevation Above Base Depth (km)
Lord Howe
Mascarene
Ontong Java
Shatsky
2900 kg/m3
2800 kg/m3
2700 kg/m3
35
30
25
20
15
10
5
0
−1
0
1
2
3
4

Figure 5.

Example: what is the thickness of continental crust at sea level as predicted by the Airy Compensation model.

$e = 5.5$ km

$h_t = 31$ km

VIEWGRAPH

CONCLUSIONS

- Typical Oceanic crust is about 6 km thick
- Typical Continental crust is about 35 km thick
- Airy compensation explains increased crustal thickness beneath oceanic plateaus
- Continental lithosphere with its thicker crust is in isostatic balance with oceanic crust

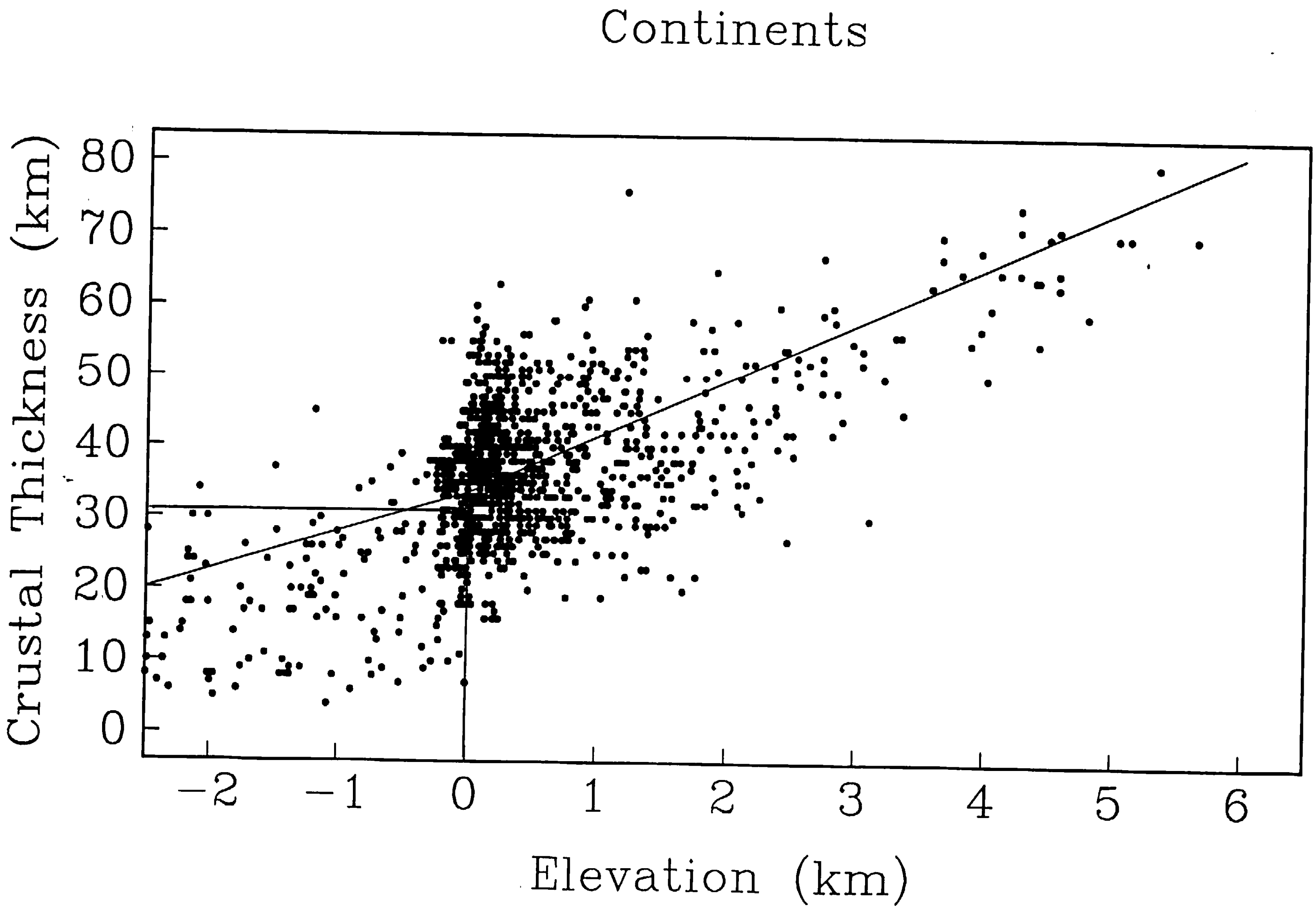
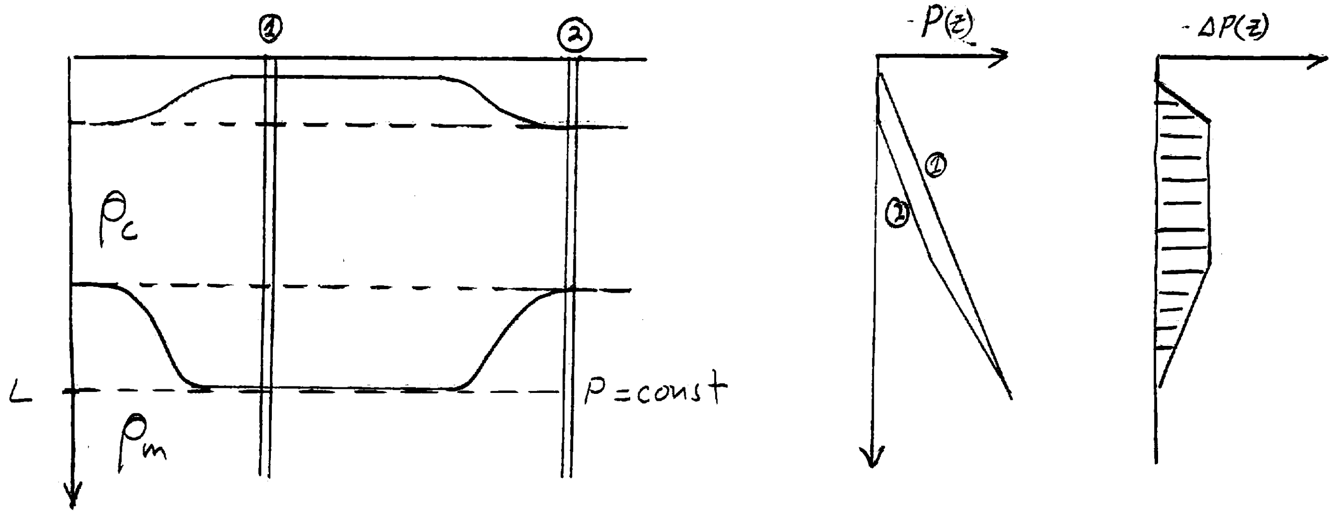

Continents
Crustal Thickness (km)
0
10
20
30
40
50
60
70
80
Elevation (km)
−2
−1
0
1
2
3
4
5
6

Figure 6.

Outward pressure due to isostatically compensated topography



$$\Delta P(z) = g\int_0^z \Delta\rho(y)\,dy \qquad \frac{\text{force}}{\text{area}} \qquad \Delta P(L) = 0$$

total outward force $F_s = \int_0^L \Delta P(z)\,dz \qquad \frac{\text{force}}{\text{length}}$

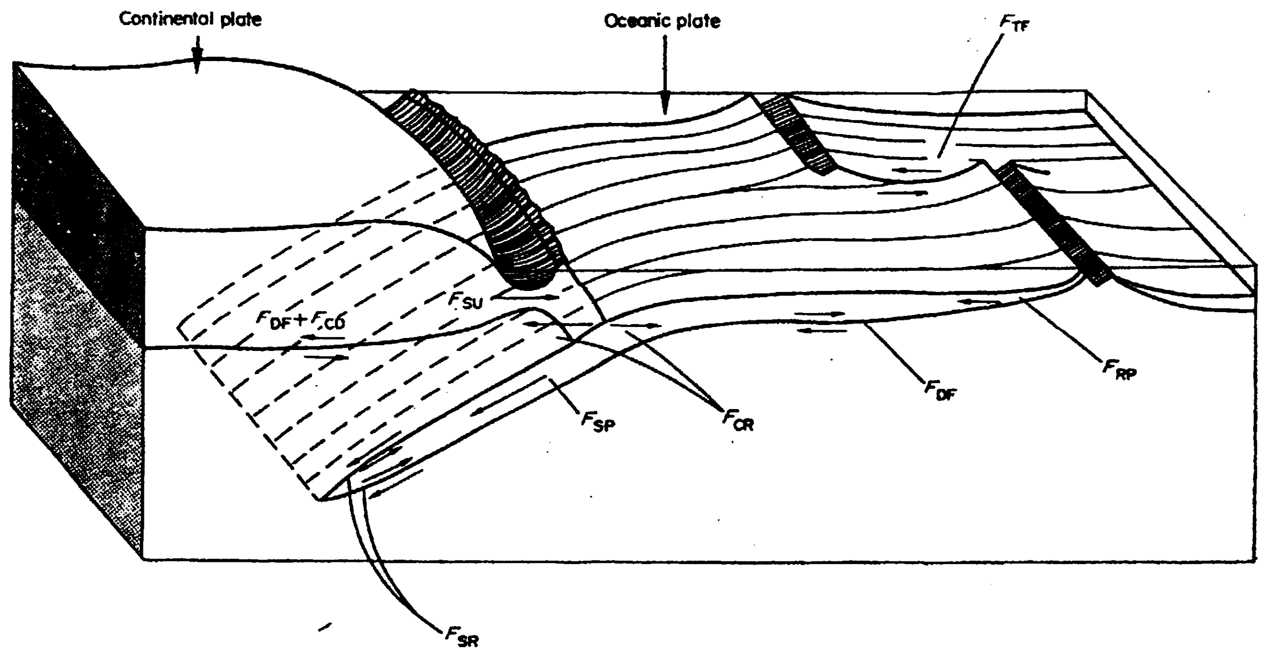
integrate by parts $\int u\,dv = uv - \int v\,du \qquad u = \Delta P(z) \quad dv = dz \quad du = \frac{\partial}{\partial z}\Delta P \quad v = z$

$$F_s = \Delta P(z)\, z \Big|_0^L{}^{\,0} - \int_0^L z \frac{\partial \Delta P}{\partial z}\,dz \qquad \frac{\partial \Delta P}{\partial z} = g\,\Delta\rho(z)$$

$$\boxed{F_s = g\int_0^L \Delta\rho(z)\, z\, dz}$$

moment of density anomaly

What is a typical ΔP for Tibet $\quad g = 10 \quad \Delta\rho = 2800 \quad h = 5000 \quad = 140$ MPa


Continental plate
Oceanic plate
F_{TF}
F_{SU}
$F_{DF}+F_{CD}$
F_{RP}
F_{DF}
F_{SP}
F_{CR}
F_{SR}

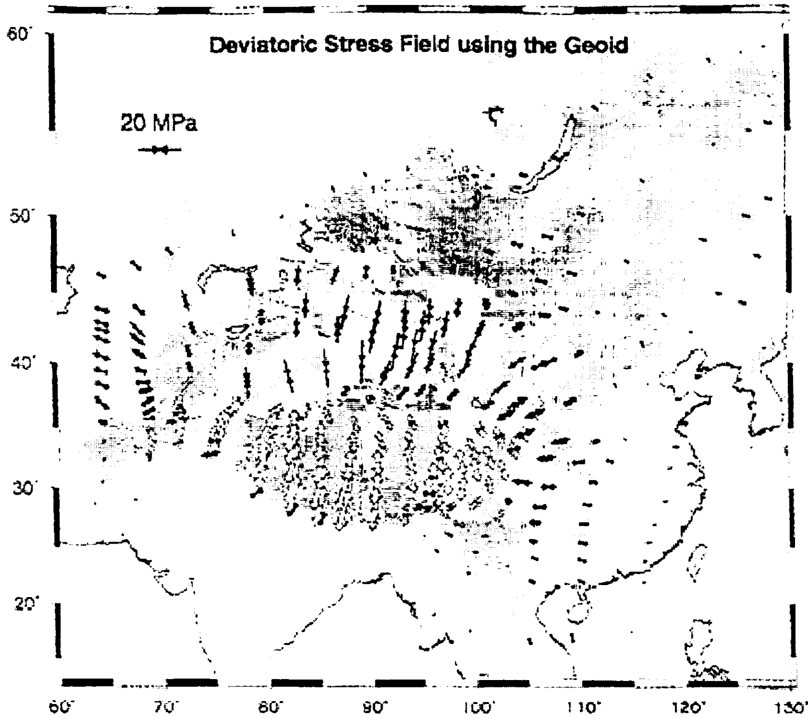


Figure 2b. Same as Figure 2a only GPE estimates were inferred from the EGM 96 geoid model.

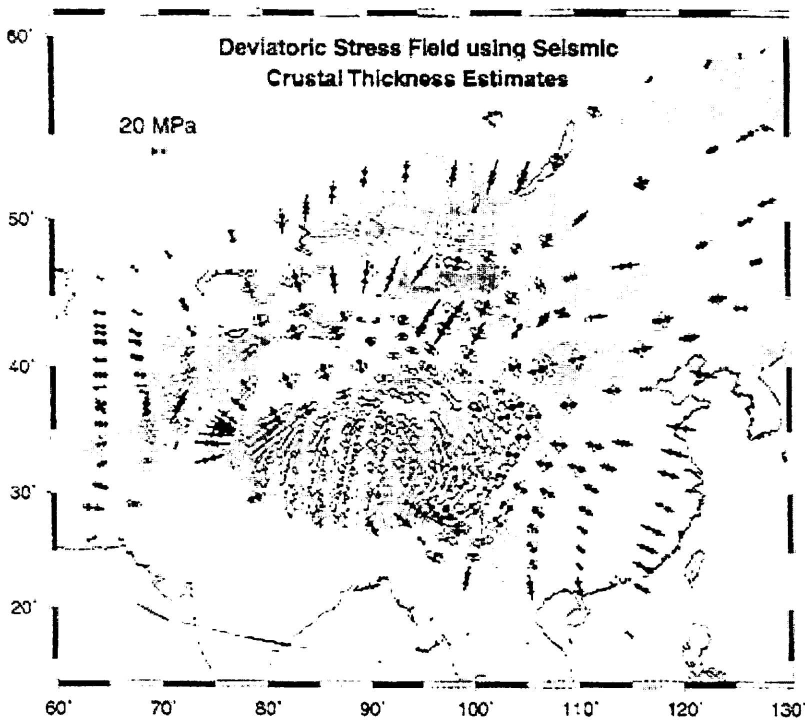


Figure 2c. Same as Figure 2a only GPE estimates were inferred using seismic crustal thickness estimates determined from surface wave data in Asia (G. Laske and G. Masters, http://mahi.ucsd.edu/Gabi/sediment.html, 2000).

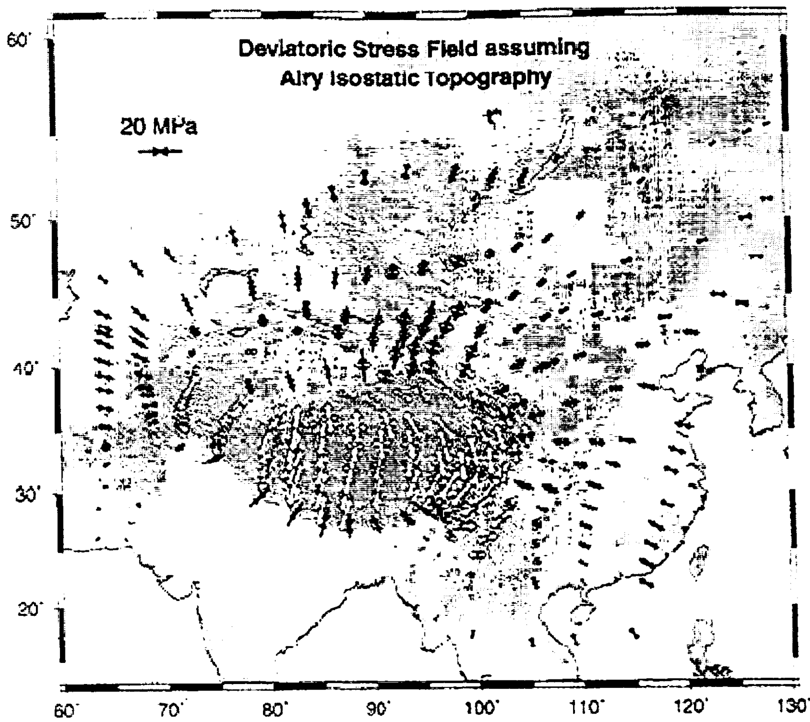


Figure 2a. The minimum root mean square deviatoric stress field that satisfies force balance equations, where sources of stress are gravitational potential energy differences (GPE) inferred assuming local Airy isostatic compensation of topography in Asia. Open principal axes represent tensional deviatoric stress. Solid axes are principal compressional deviatoric stress.