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LITHOSPHERIC BULGE AND THICKENING OF THE LITHOSPHERE WITH AGE

EXAMPLES IN THE SOUTH-WEST PACIFIC

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- INTRODUCTION :

The lithospheric bulge before its underthrusting beneath an island arc has been studied in several previous works, Gunn (1943), Lliboutry (1969-1973), Walcott (1970), Hanks (1971), Dubois et al (1973,1974,1975), Watts and Talwani (1974). Those studies have shown that the flexural parameter might be computed from the elastic plate deflection which the lithosphere is assimilated to, and therefore to derive its thickness.

That thickness has been derived to be approximately equal to the half of the lithospheric one as it can be defined from the seismic wave propagations, its basement being the upper boundary of the low velocity layer. Turcotte (1974) points out that at 25 km deep the temperature is about 300° C, from that observa-

of the New Hebrides trench to part from the theoretical model appears to be explained (Dubois et al, in press) through the plastic properties of the extremity of the plate at the level of its dipping with a rupture of the solid crust in surface.

The lithospheric thickness depends essentially on the criterium of definition chosen for that concept. We have seen before that the seismology and the flexure gave different values in thickness. If we consider with Schubert et al (1976) a thermal and mechanical solid state model, we can give with them a third definition of the lithospheric thickness : if u_0 is the constant lithospheric velocity in surface with regard to the deep mantle, we call lithosphere the layer where the horizontal velocity u with regard to the same referential, is such as $u \geq 0.95\ u_0$ (fig.4).

[redacted]

as a consequence of its deformation. The previous works which have been made (Dubois et al 1973,1975) allow the computation of a flexural parameter of about 76 ± 5 km say a thickness of the elastic lithosphere of 24.2 ± 2.1 km.

The Tonga-Kermadec lithosphere.

On the Tonga-Kermadec we use bathymetric and seismic profiles carried out during the GEORSTOM III cruise. The four profiles (fig.1) from 318 to 321 cross the arc from the 35°S to the 23°S. They have been surveyed with respect to the trend perpendicular to the trench axis, the sedimentary layer is thin, 0.1 s two way travel North and 0.4 s.t.w.t. South. This is the reason why the study of the deflection has been surveyed across the bathymetric profiles and not, as Caldwell et al (1975) suggested on the acoustic basement after stripping sedimentary cover.

It seems too that the profile 318 which brings out the sediment thickness, the more important, is different enough from the others the outer wall of the trench is accretionary in type (connected with the sediments on the underthrusting plate ?) while on the three other profiles we have to deal with outer wall non-accretionary in type, as Fisher and Engel (1969) assumed through their dredging on the Tonga trench close to the profile 321 (fig.2).

One can note too that the trench dept increases from South to North from 7900 m deep on 318 to 10900 m on 321. That deepening of the trench with the increase of the distances from the rotation center of both plates underthrusting and overthrusting (here the rotation center is South of New Zealand) may be observed everywhere (Dubois et Recy, in prep.). On the outer wall a fracturation appears which has yet been mentioned previously in this study, at the level of separation from the theoretical curve. This fracturation certainly depends on the crust heterogeneity. It is as much important as the lithosphere is more heterogeneous, seamounts, fractures (see profiles 319 and 320 close to the intersection of Louisville Ridge with the subduction zone).

By means of a hand smoothing of the bathymetric profiles, we obtain a good scheme of the bulge where it is easy to measure the pseudo wavelength π/λ and the bulge amplitude (see appendix a). We can also filter the rough data with a low frequency filter which removes the short wavelengths of the topographical background superposed on to the here studied phenomenon.

The filter used here (see appendix b and fig. 3) is a symmetrical (to prevent the difference in phase) linear filter. It is a low frequency filter which we have applied with a cutoff frequency corresponding to the removal of the reliefs of less than 60 km wide. At the extremities of the profiles to prevent the removal of one wavelength, we have prolongated the profiles to 60 km more with a constant depth.

The obtained results in the measurements of the distances between two successive zeros and the corresponding values of the flexural parameter and of the elastic model thickness are noted in the Table I. For the theoretical meaning of those parameters, see Hanks (1971), Dubois et al (1974,1975). ζM corresponds to the bulge amplitude.

In spite of the inaccuracies in the reading, we can assume that a very small increase of the flexural parameter may be shown directed South to North. That increase coincides too with a small deepening of the bottom : 5880 m for the profile 318, 5940 m for the profile 319, but 5760 m for the 321.

- CORRELATIONS WITH THE AGE CRITERIUM

Let us examine those results through the previous works made about the oceanic lithosphere. It has been emphasized that an oceanic lithosphere was deepening with time and that it was thickening (Parker and Oldenburg 1973). Recently, Schubert et al (1976) proposed a coupled thermal and mechanical solid state model of the oceanic lithosphere and asthenosphere which includes vertical conduction of heat with a temperature dependant thermal conductivity, horizontal and vertical advection of heat, viscous dissipation or shear heating and linear or non linear deformation mechanisms with temperature and pressure dependant constitutive relation between shear stress and strain rate (see appendix c).

In this model, in addition to the numerical values of the medium properties, the lithospheric velocity values of the plate in surface, the temperatures at the surface and a great depth are arbitrarily chosen (to integrate the differential equation giving the temperature distribution). The model determines the depth and age dependant temperature, horizontal and vertical velocity and viscosity structure of the lithosphere and asthenosphere. Particularly we can derive the oceanic floor topography, the oceanic heat flow and the lithosphere thickness as function of the age of the ocean floor. The rate of growth of the lithosphere decreases with age.

In their theoritical work Schubert et al (1976) were arguing, on their model, about applying or not the Newton's law on solid deformations (proportionality between the stress deviator and the velocity deformation). In laboratory on deformed olivine that behaviour has never been observed, because they are non Newtonian processes based on the dislocation movements (Weertman 1970) which are prevailing rather than diffusion between the grains under the applied stresses (Nabarro 1948). The peridotitic flexural nodules show sub-grained structures and dislocation densities equal to those of the laboratory samples. Therefore, we can expect the non Newtonian behaviour to be prevailing in the asthenosphere where the peridotitic nodules are supposed to form.

As for Schübert et al, from 1000 km towards the ridge, say at 10 M.y, (spreading rate of 10 cm/y), the dislocation mechanism is prevailing with regard to a relatively cold mantle. Thence, it is the non-Newtonian model which will be applied to the case we are studying, that of the New Hebrides and Tonga Kermadec. (fig. 5).

The empirical curve of the water depth - (age)1/2 given by Parsons and Sclater (1976)

- Appendix a -

- Lithospheric bulge

The deflection equation of an elastic thin sheet semi infinite where a horizontal force Nb and vertical force Pb are applied on the free boundary is :

$$\zeta = \frac{-\,Pb}{\beta\ (\rho m - \rho w) g} \cdot \frac{2\lambda^2}{3\alpha^2 - \beta^2} \cdot e^{-\alpha x}\{2\alpha\beta \cos \beta x + (\alpha^2 - \beta^2) \sin \beta x\}$$

in which $\lambda = \{(\rho m - \rho w) g/4\ \Gamma\}^{1/4}$

$\Gamma = E\ H^3/12(1 - \sigma^2)$

$\alpha = (\lambda^2 + Nb/4\ \Gamma)^{1/2}$

$\beta = (\lambda^2 - Nb/4\ \Gamma)^{1/2}$

where σ = Poisson's ratio

E = Young's modulus

H = thickness of lithospheric plate

ρm, ρw = densities above and below the plate respectively

Pb, Nb = vertical and horizontal

- Appendix b -

- Filtering

To remove the bathymetric background we computed and applied to the data a linear [illegible]

[illegible]

quency of the filter is :

$$W(p) = W_o + 2\ \Sigma_{k=1}^{N}\ Wk \cos \pi k\ p, \text{ where } p=\frac{f}{fc}$$

is the reduced abscissa.

[illegible]

ρ = density
Cp = specific heat
K = thermal conductivity
τ = shear stress parallel to a horizontal surface

The rheological law connecting shear stress and strain rate :

$$\frac{\partial u}{\partial y} = - \frac{2\ Bn}{T} \quad \tau^n \exp \{- \frac{(E^\bigstar + pV^\bigstar)}{RT} \} \qquad (3)$$

$E^\bigstar$ = activation energy
$V^\bigstar$ = activation volume
p = pressure
R = gaz constant
Bn = proportionality factor
n = 1 for Newtonian flow
n > 1 for non Newtonian flow here n = 3 (deformation of olivine)

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- DUBOIS J., LAUNAY J. and RECY J. - 1974 - Uplift movements in New Caledonia - Loyalty Islands arc and their Plate-Tectonics interpretation - Tectonophysics 24, 133-150.

- DUBOIS J., LAUNAY J. and RECY J. - 1975 - Some new evidence on lithospheric bulges close to island arcs. Tectonophysics 26, 189-196.

- DUBOIS J., DUGAS F., LAPOUILLE A. and LOUAT R. - (Vancouver Congress 1975) - The troughs at the rear of the New Hebrides in island arc : possible mechanisms of formation. Canadian Journal of Earth Sciences (in press).

- DUBOIS J. et RECY J. - Evolution dans le temps des zones de subduction : comparaison entre les zones fossiles et actives (in prep.).

- FISHER R.L. and ENGEL C.G. - 1969 - Ultra-

- SCHUBERT G., FROIDEVAUX C. and YUEN D.A. - 1976 - Oceanic lithosphere and asthenosphere : Thermal and mechanical structure. J. Geophys. Res. 81-3525-3540.
- TURCOTTE D.L. - 1974 - Arc transform faults thermal contraction cracks. Cornell Univer-
- WATTS A.B. and TALWANI M. - 1974 - Gravity anomalies seaward of deep-sea trenches and their tectonics implications. Geophys. J. R. Astron. Soc. 36, 57-90.
- WEERTMAN J. - 1970 - The creep strength of

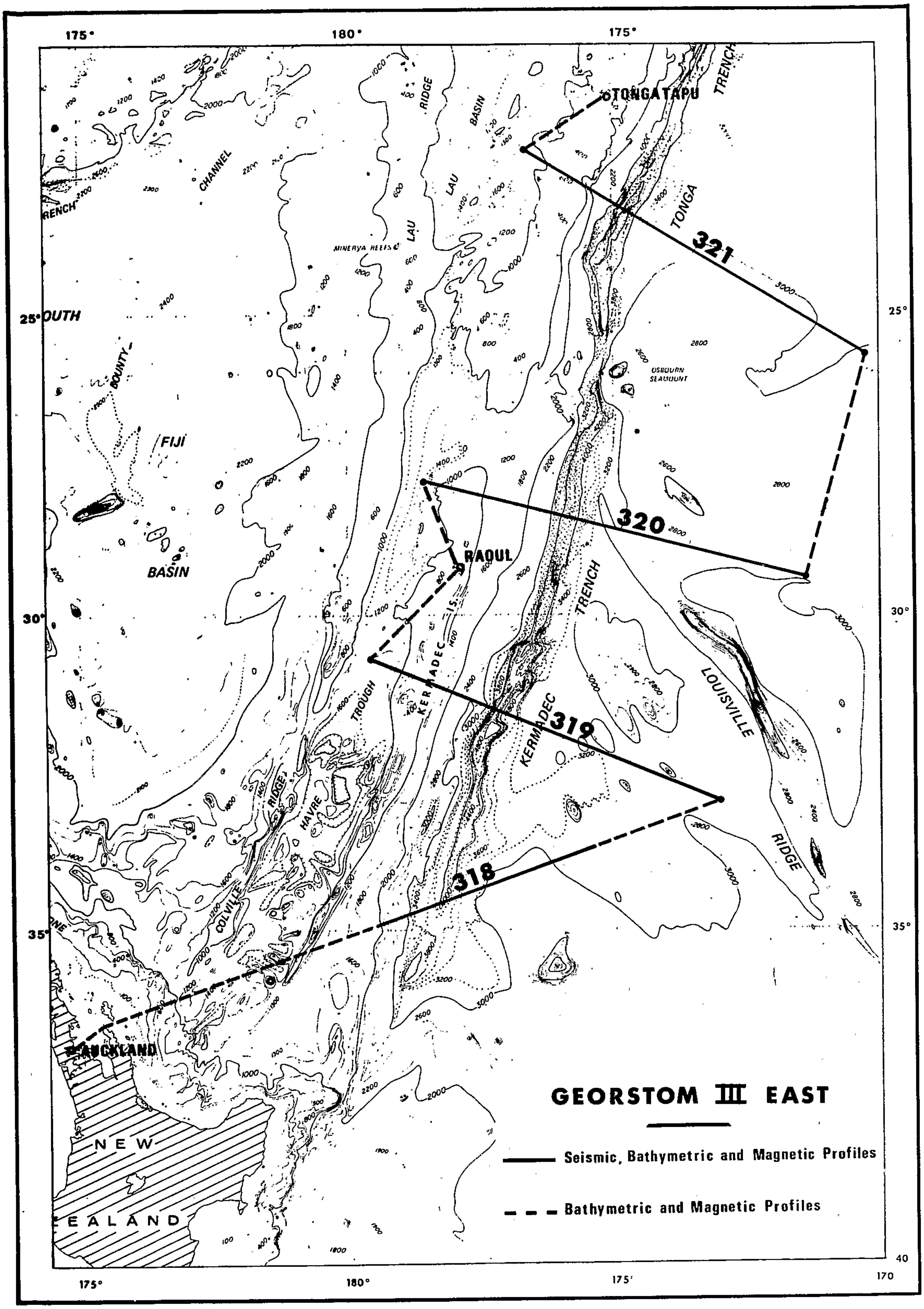

Fig. 1 - Tonga and Kermadec Trenches - Bathymetry and location of GEORSTOM III East profiles.

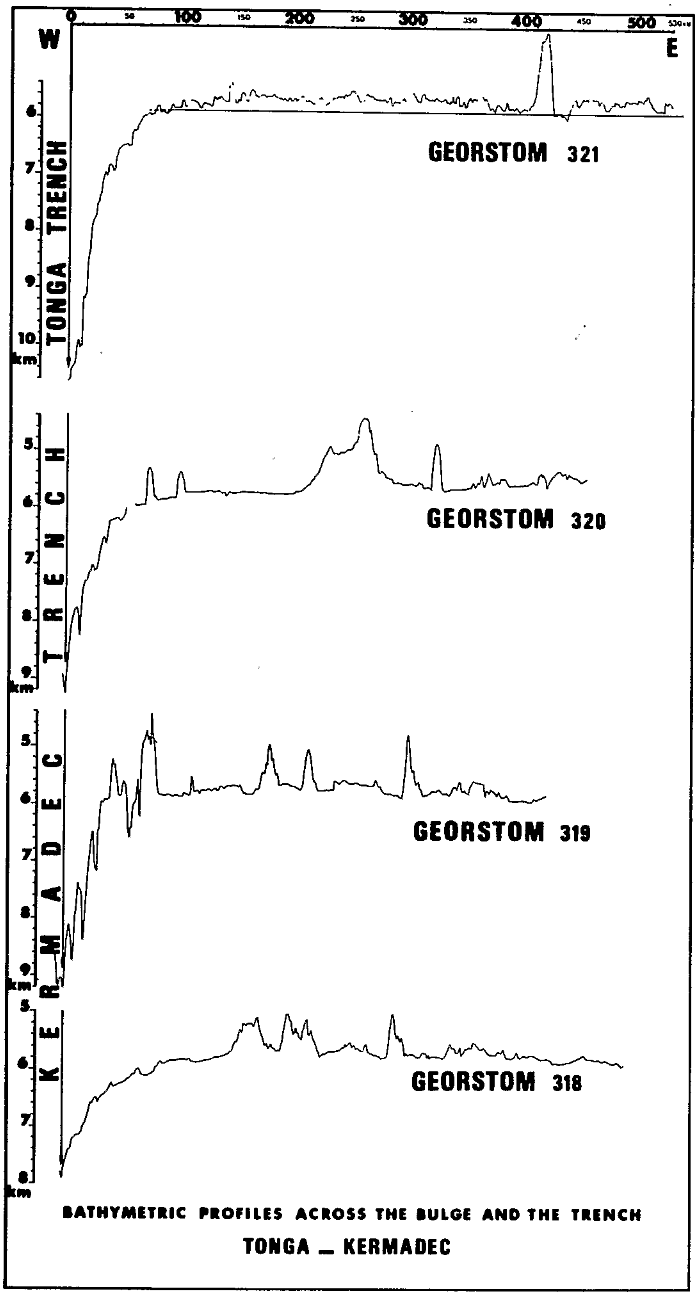

Fig. 2 - Bathymetric profiles of GEORSTOM III East cruise.

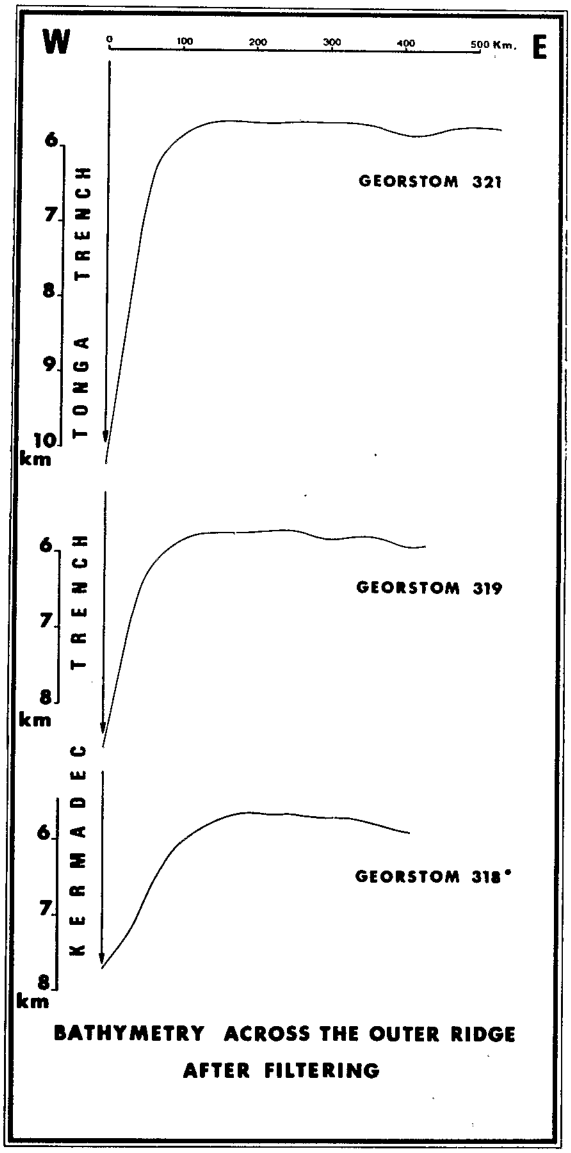

Fig. 3 - Bathymetry of GEORSTOM III East profiles after filtering. (★ Profile 318 is rabatted on a line perpendicular to the trench).

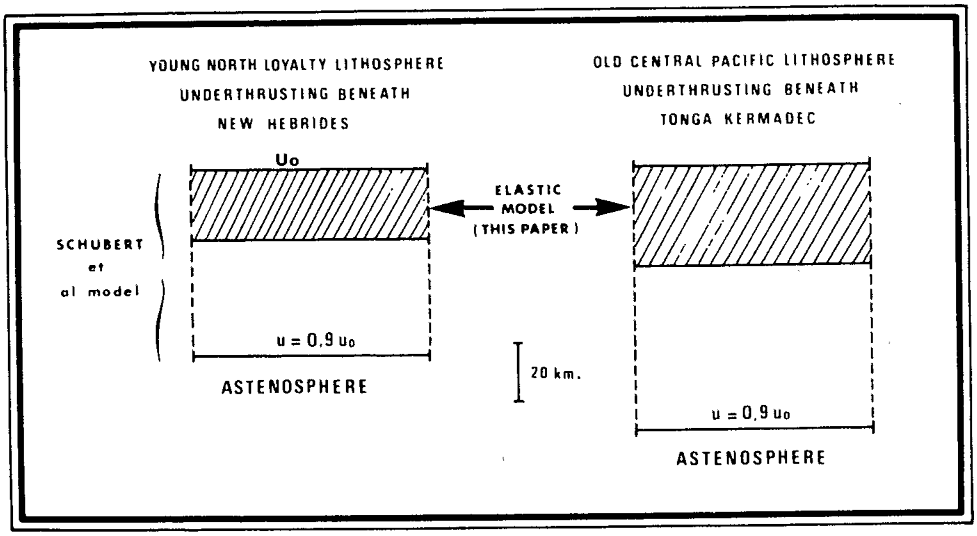

Fig. 4 - Comparison between the lithospheric thickness from Schubert et al (1976) and the elastic model (this paper).

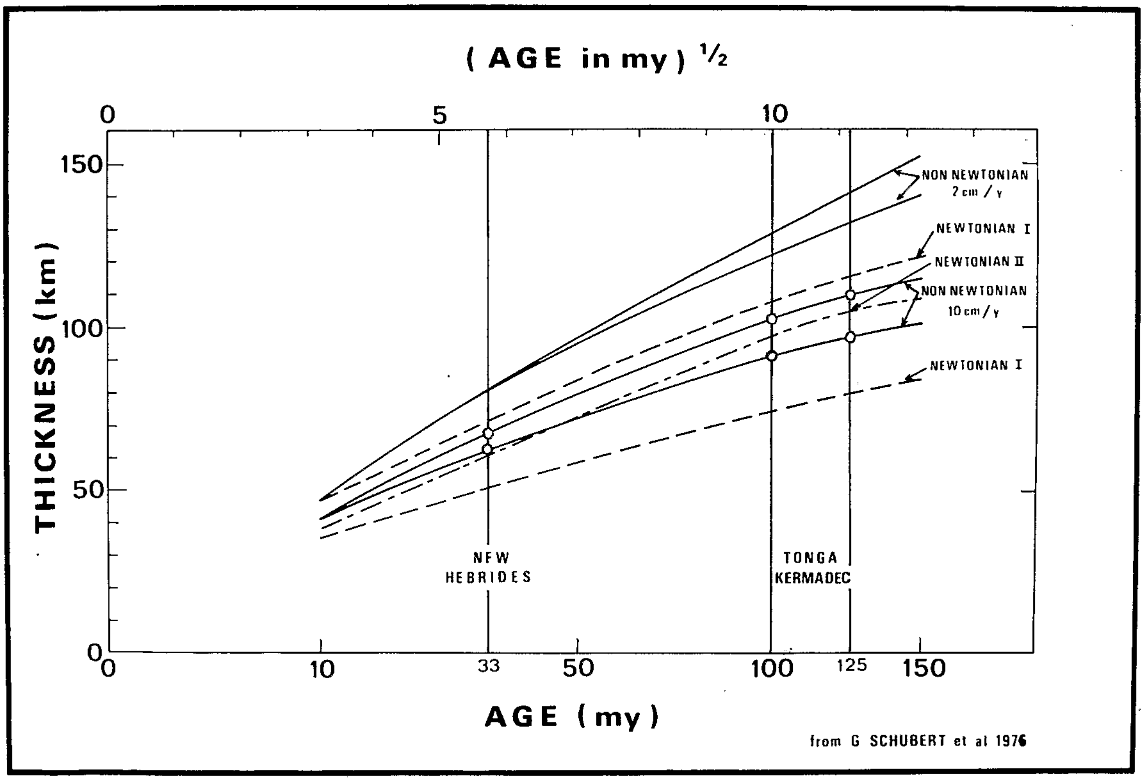

Fig. 5 - Newtonian and Non-Newtonian model curves from Schubert et al (1976).

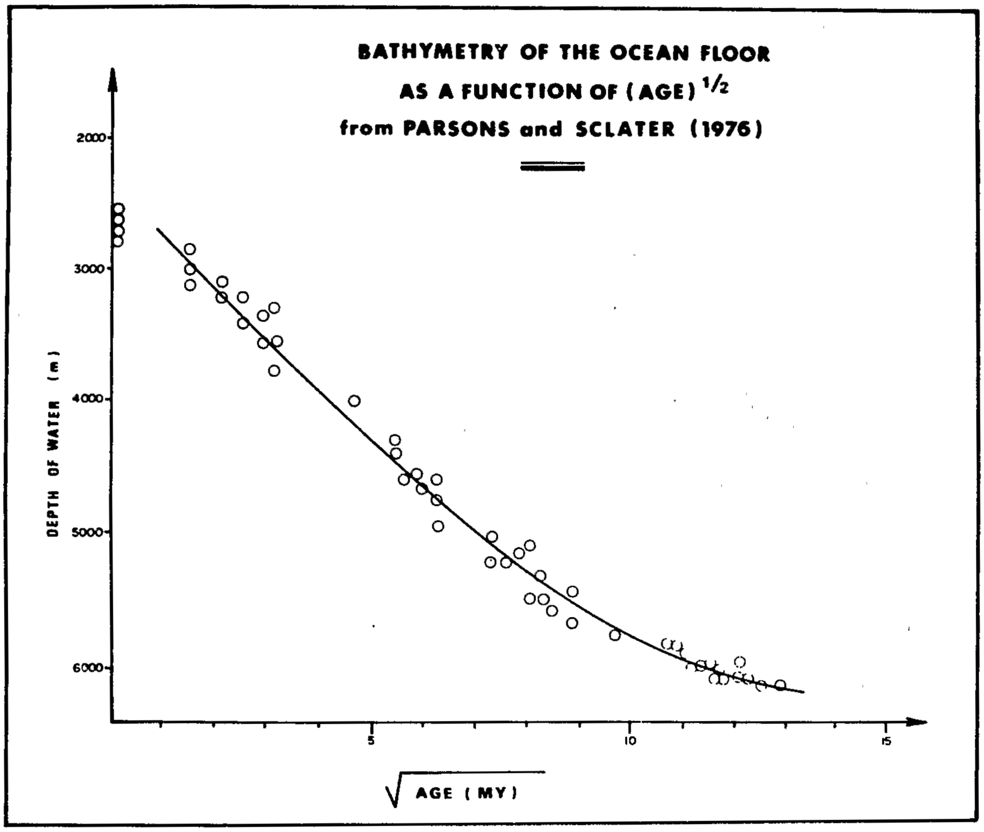

Fig. 6 - The empirical curve of the water depth - $(age)^{1/2}$ from Parsons and Sclater (1976).

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