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THERMAL ASPECTS OF SOME GEODYNAMICAL MODELS OF THE TYRRHENIAN OPENING

Abstract. Thinning of the lithosphere caused by passive or active upwelling of the asthenosphere has been thermally modelled to explain the very high heat flow observed in the Tyrrhenian basin. No comparison is made between the models, because information about the structure of the Tyrrhenian crust is not sufficient. Much is expected from the seismic CROP - Mare Project.

INTRODUCTION

All the geodynamical models proposed to explain the opening of the Tyrrhenian sea can be grouped for geothermal modelling into the following:

i) thinning of the lithosphere caused by tensile forces in the back-arc and passive upwelling of the asthenosphere, which degenerates into central rift where oceanic crust is created;

ii) thinning of the lithosphere caused by active upwelling of the asthenosphere;

iii) thinning of the lithosphere followed by separation of plates due to retrogradation of the subduction hinge, and passive upwelling of the asthenosphere.

Of these, only model i) has been thermally modelled.

The aim of this work is a short review of model i) and a first proposal for the thermal modelling of ii) and iii).

HEAT FLOW DATA

Della Vedova et al. (1991) have recently compiled a heat flow density map of the Tyrrhenian sea and surroundings areas using an interpolation program for data irregularly distributed over a plain, which employs cubic splines (Loddo and Zito, 1989). This map (Fig. 1) shows a very high regional heat flow and strong local maxima and minima in areas of recent tectonic and volcanic activity and of probable surficial convective water movements. To obtain the regional field, the map has been filtered using several cut-off wave lengths.

Fig. 2 shows the field obtained using the cut-off wave length $L=150$ km; this is assumed as representative of the regional field, because in this map the local anomalies disappear, and for $L>150$ km the field remains practically unchanged.

The residuals are of small extent, high intensity (over 100 mWm^{-2}), and all located on the eastern side of the Tyrrhenian basin.

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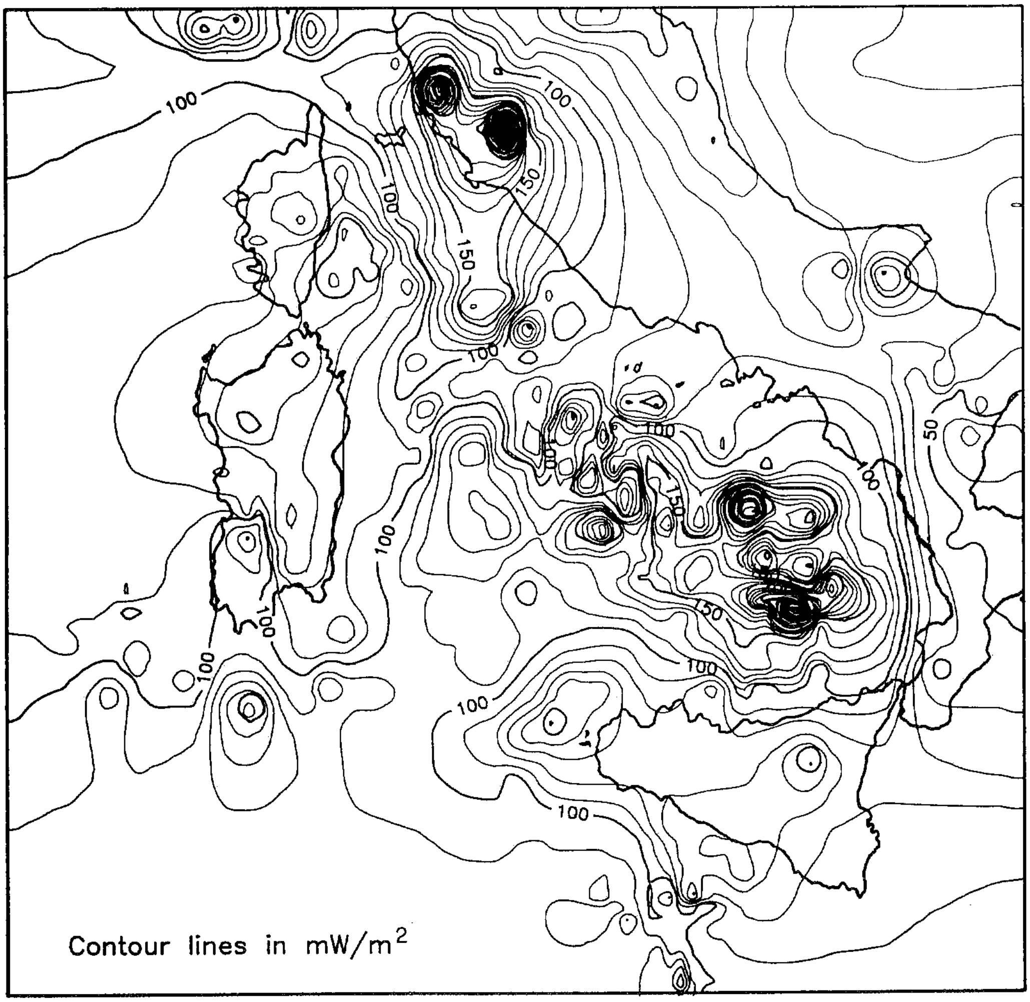


Fig. 1 - Heat flow density map of the Tyrrhenian Sea.

Throughout the Tyrrhenian sea, the heat flow density is over 100 mWm^{-2}; and the maximum is located on the southeastern sector of the basin where it reaches the value of 170 mWm^{-2}.

MODEL I

Malinverno (1981), Malinverno et al. (1981), Huchison et al. (1985) suppose that the Tyrrhenian basin was created behind an eastward migrating trench system by the stretching of the lithosphere. Huchison et al. (1985) applied the simple stretching model of Mc Kenzie (1978) to the Western Tyrrhenian (HFD$=134\pm8$ mWm^{-2}) and obtained a very high stretching factor (β»6). They mantain that, when stretching is long and continuous, oceanic crust is created in a central rift (Fig. 3). They modelled this phase in the Southern Tyrrhenian (HFD$=151\pm10$ mWm^{-2}) with the oceanic plate model (Parson and Sclater, 1977) which corresponds to $\beta=\infty$.

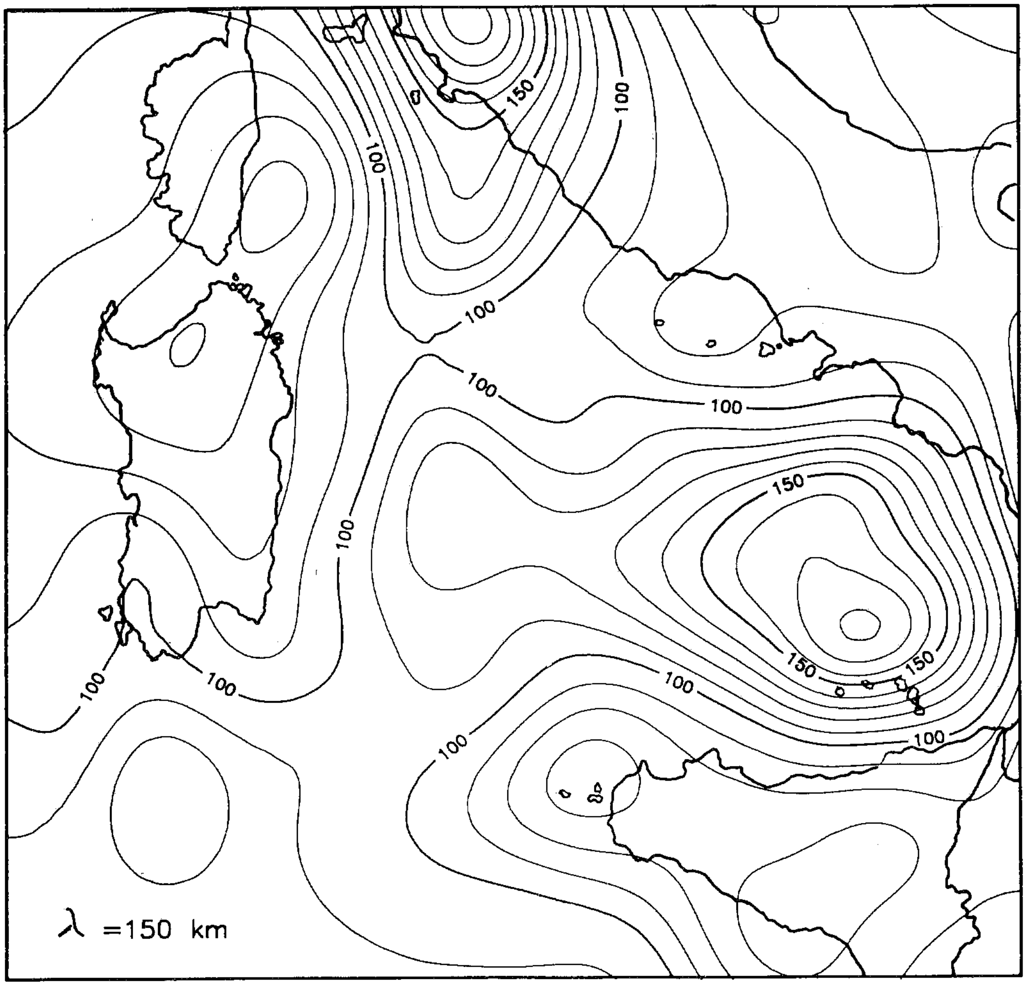


Fig. 2 - Low-pass filtered heat flow density map of the Tyrrhenian Sea (cut-off wave length=150 km).

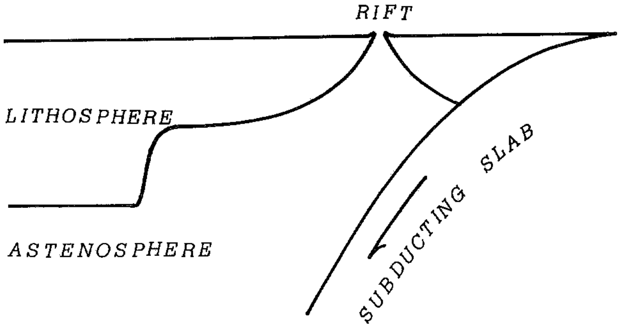


Fig. 3 - Back-arc basin formed by simple lithospheric stretching, and central rift.

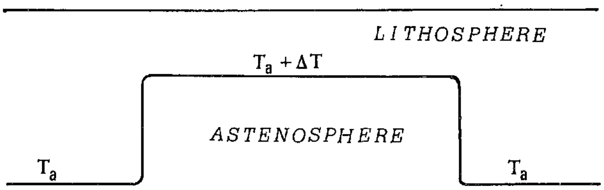


Fig. 4 - Thermal model of an asthenolith.

MODEL II

Locardi (1985) deduces that the Tyrrhenian basin is due to the active rising of an asthenolith, which thins the lithosphere.

Let us consider (Fig. 4) a stable lithosphere which at time t=0 reduces to the thickness l with the following definitions:

T_0=the surface temperature,

G=the mean crustal geothermal gradient,

T_a=1300°C the temperature of the stable asthenosphere,

ΔT=the temperature excess of the asthenosphere.

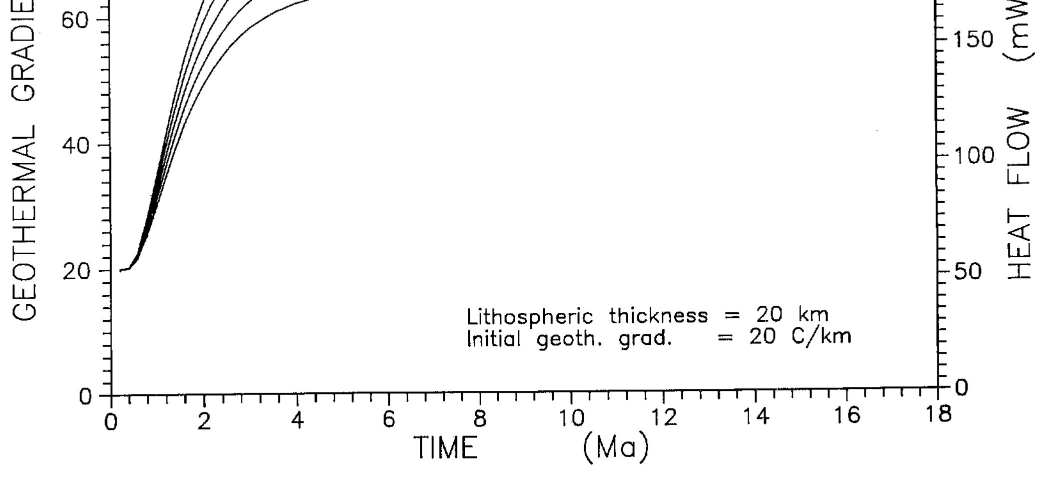
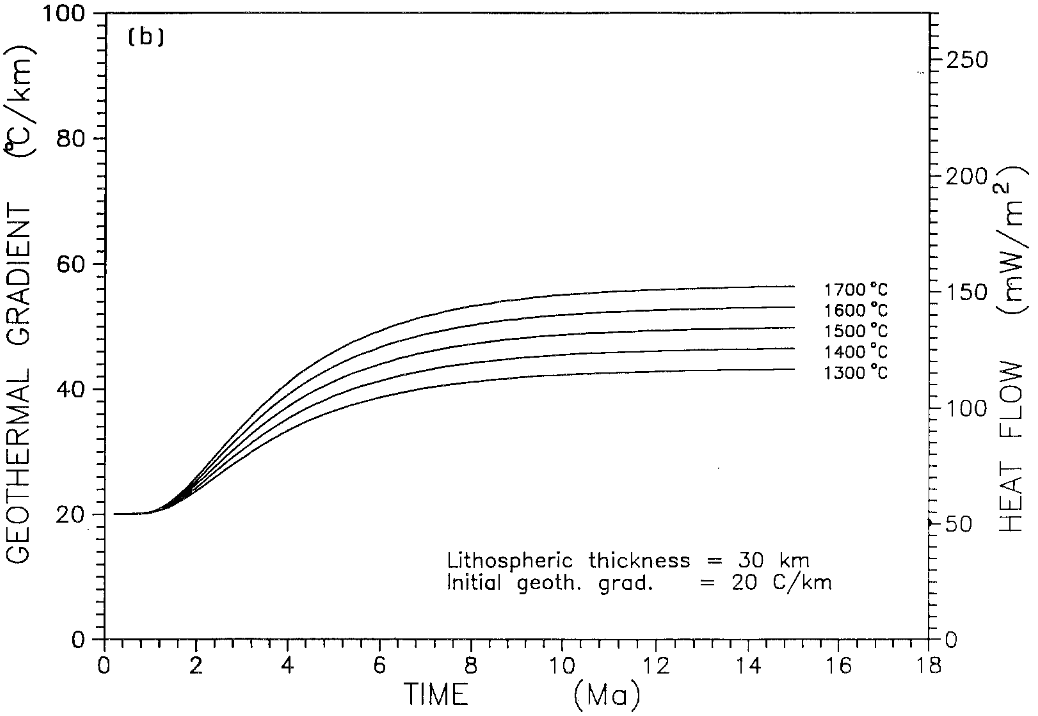
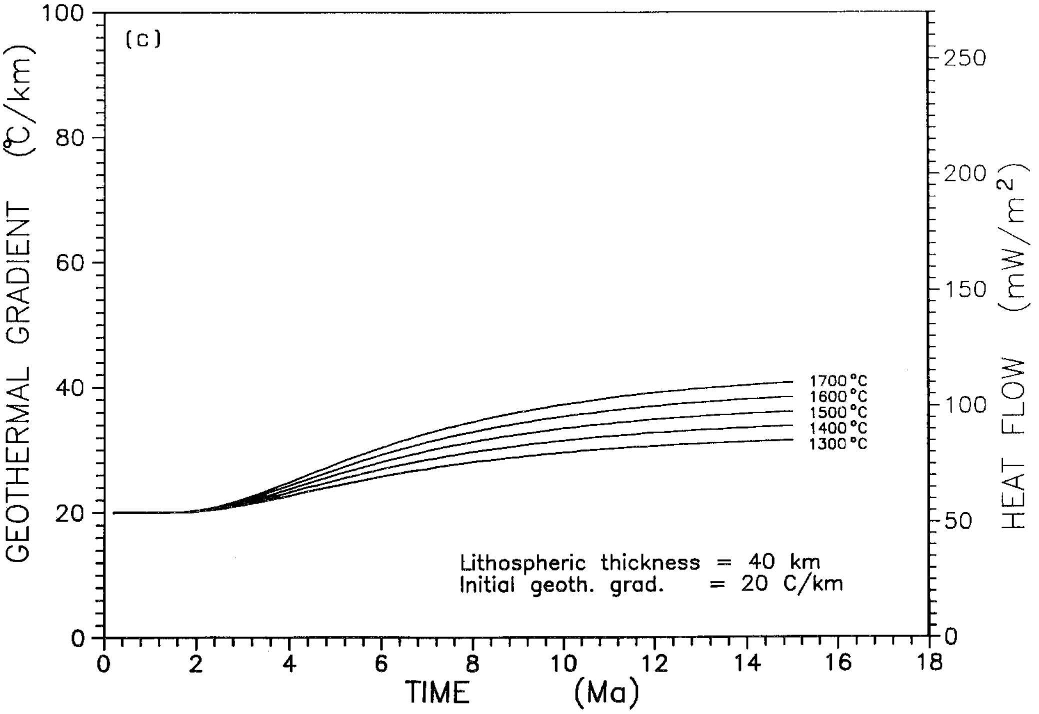


Fig. 5 - Theoretical increase of heat flow density as a consequence of a sudden asthenolith rise, for a) 20 km lithospheric thickness; b) 30 km lithospheric thickness; c) 40 km lithospheric thickness.


(b)
GEOTHERMAL GRADIENT (°C/km)
HEAT FLOW (mW/m^2)
TIME (Ma)
0
20
40
60
80
100
0
50
100
150
200
250
0
2
4
6
8
10
12
14
16
18
1700 °C
1600 °C
1500 °C
1400 °C
1300 °C
Lithospheric thickness = 30 km
Initial geoth. grad. = 20 C/km


(c)
GEOTHERMAL GRADIENT (°C/km)
HEAT FLOW (mW/m^2)
TIME (Ma)
0
20
40
60
80
100
0
50
100
150
200
250
0
2
4
6
8
10
12
14
16
18
1700 °C
1600 °C
1500 °C
1400 °C
1300 °C
Lithospheric thickness = 40 km
Initial geoth. grad. = 20 C/km

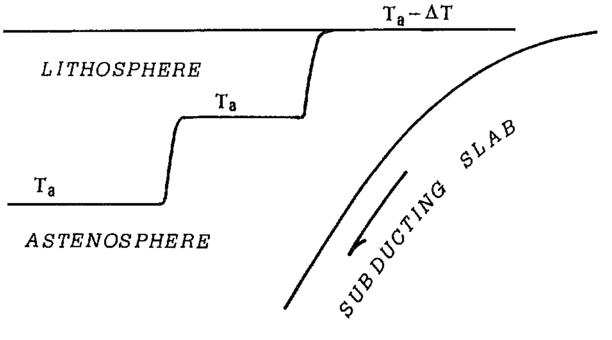


Fig. 6 - Thermal model of asthenospheric upwelling by diverging plates.

Then the temperature at depth 1, which is T_o+G1, at time $t=0$ suddenly becomes $(T_a+\Delta T)$.

Thus the temperature in the layer 1 for $t>0$ is given by (Carslaw and Jaeger, 1959)

$$T\ (z,t)=To+\frac{T_a+\Delta T-To}{z}l+$$

$$+\frac{2}{\pi}\sum_{1}^{\infty}\frac{(T_a+\Delta T)\cos n\pi-T_o}{n}\sin\frac{n\pi z}{l}\exp\left(-\frac{k n^2\pi^2 t}{l^2}\right) \qquad (1)$$

$$+\frac{2}{\pi}\sum_{1}^{\infty}\sin\frac{n\pi z}{l}\exp\left(-\frac{k n^2\pi^2 t}{l^2}\right)\left[\frac{T_o-(T_o+G\,l)\,(-1)^n}{n}\right],$$

where z is the axis oriented downward, and k is the themal diffusivity.

By assuming $T_o=0$, the surface heat flow is given by

$$q=\lambda\left(\frac{\partial T}{\partial z}\right)_{z=0}=\lambda\left[\frac{T_a+\Delta T}{l}+2\left(\frac{T_a+\Delta T}{l}-G\right)\sum_{1}^{\infty}(-1)^n\exp\left(-\frac{kn^2\pi^2t}{l^2}\right)\right], \qquad (2)$$

where λ is the thermal conductivity.

If we take

λ = 2.7 $Wm^{-1}\ k^{-1}$,
1 = 20, 30, 40 km,
G = 20°C/km,
$T_a+\Delta T$ = 1300, 1400, 1500, 1600, 1700°C,

then the curves of Fig. 5 are obtained.

From these we deduce that to obtain a HFD of 170 mWm^{-2} which is about three times the normal HFD (50-60 mWm^{-2}), the asthenolith must have a temperature some hundreds of degrees higher than the reference temperature of the upper asthenosphere (1300°C).

MODEL III

Doglioni (1991) has recently proposed for the Tyrrhenian Sea the model of a back-arc

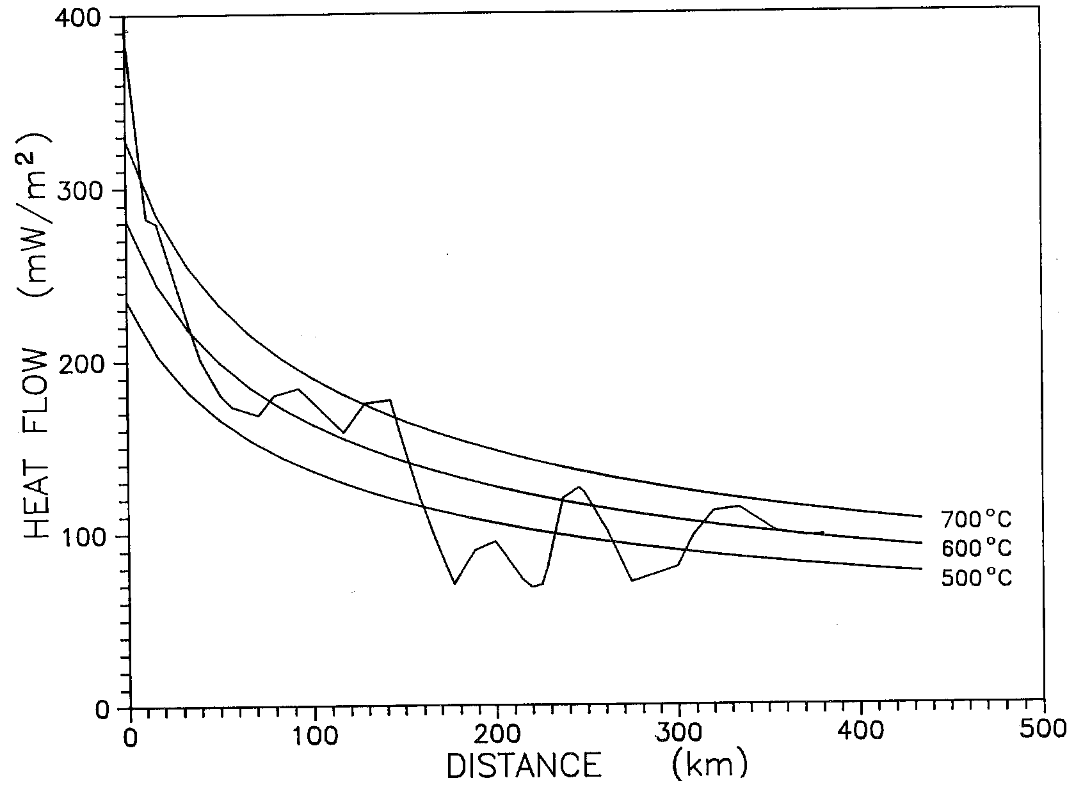


Fig. 7 - ESE-WNW profile of the observed Tyrrhenian heat flow and the theoretical decrease of heat flow versus the distance from the maximum.

basin associated with a plate subducting against the eastward flow of the asthenosphere. Mongelli et al. (1994) mantain that, as mature stage of the subductions, the converging plates may diverge, because:

a. the subducted plate anchors in the asthenosphere and assumes a velocity greater than the overthrusting plate;

b. the asthenospheric flow bends an increasing part of the subducting plate, so that the plates separate.

As a consequence, the asthenosphere may rise up to the earth's surface, while its temperature decreases due to adiabatic expansion by a quantity ΔT.

This can be modelled by a half-space at temperature $(T_a - \Delta T)$ whose surface temperature is T_o at $t=0$. The solution is

$$\frac{T-T_o}{(T_a-\Delta T)-T_o} = \mathrm{erf}\left(\frac{z}{2\sqrt{kt}}\right). \tag{3}$$

The surface heat flow is

$$q=\lambda\left(\frac{\partial T}{\partial z}\right)_{z=0} = \frac{\lambda\,(T_a-\Delta T-T_o)}{\sqrt{\pi kt}}. \tag{4}$$

By indicating with

$v = x/t$ the differential velocity of the diverging plates,
x the increasing distance,

eqn. (4) may be written

$$q = \lambda \frac{(T_a - \Delta T) - T_o}{\sqrt{\pi k \, x/v}} . \tag{5}$$

By assuming

$\lambda = 3 \mathrm{W m^{-1} k^{-1}}$,
$k = 10^{-5} \mathrm{m^2 sec^{-1}}$,
$T_a - \Delta T$ = 400-500-600°C,

we obtain the curves of Fig. 6.

In this case we compare the theoretical curves with the observed heat flow, because we interpret the highest values as due to the emersion of the asthenosphere.

From the Fig. 5 one can see that a temperature of 500-600°C is sufficient to explain the observed heat flow, disregarding the effect of hydrothermal circulation at the seabed.

CONCLUSIONS

Each of the models illustrated needs an accurate knowledge of the crustal structure of the Tyrrhenian basin to permit improvements, comparisons and criticism of the models. Therefore we expect much from the Italian CROP-Mare Project.

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