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Heat Flow Measurements in Northern Italy and Heat Flow Maps of Europe

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Abstract. 26 heat flow values were determined in the northern Italian lakes. The mean is calculated to be $1.59 \mu\text{cal cm}^{-2}\text{s}^{-1}$ and after subtraction of the effect of uplift and denudation of the Alps $1.07 \mu\text{cal cm}^{-2}\text{s}^{-1}$. With regard to the results of Austria and Hungary a rise in the mean values is observed from west to east.

Heat flow maps have been constructed performing a trend analysis of all available European heat flow values. The Rhinegraben and Ivrea anomaly having a "local" character are not recognizable on the maps.

Simple transient models for the Ivrea anomaly and the two Mediterranean anomalies have been calculated to explain the present surface flow distribution.

The existence of a low velocity layer in the crust west of the Ivrea body is not in disagreement with the measured heat flow values. This does not hold for the Ivrea region itself if correction of the heat flow values for uplift and denudation is being made. However, it is perceivable that a heat wave caused by the possibly anomalous hot low velocity layer has not yet reached the earth surface or can not be detected due to the inaccuracy of the measurements.

Key words: Geothermics — Heat Flow — Trend Analysis of Heat Flow Values.

1. Introduction

Heat flow maps from Germany and Central Europe (Haenel, 1970, Haenel and Zoth, 1973, Hurtig, 1973) have already been published in the past. Unfortunately the polynomial representations always showed strong gradients near the margins not representative of the true situation. Therefore an enlarged isoline map of Central Europe is being proposed in this paper. Furthermore some new heat flow values from Northern Italy are presented.

2. Heat Flow Measurements in the Lakes of Northern Italy

Twenty-six heat flow values in 8 lakes were measured in the autumn of 1970 (Table 1). The measurements and corrections for the influence of topography, sedimentation and the annual temperature wave in the water near the bottom were carried out following Haenel (1970). For three lakes (Iseo, Sirio and Viverone) no water temperature measurements were carried out, which made it impossible to correct the heat flows individually.

Table 1. Heat flow measurements in Italian lakes. q = heat flow, q_k = heat flow corrected for uplift and denudation, B_0 = value from bore hole, TU = value from tunnel, ^a mean of two values

No.	Lake	Latitude (degree-minute)	Longitude (degree-minute)	Waterlevel (m)	Depth of water (m)	q ($\mu\text{cal cm}^{-2}\text{s}^{-1}$)	q_k ($\mu\text{cal cm}^{-2}\text{s}^{-1}$)
1	Sirio (Ivrea)	45 — 29.2	7 — 53.1	271	46	1.02 ^a	0.65
2	Viverone (Ivrea)	45 — 25.0	8 — 1.9	230	52	0.99 ^a	0.63
3	Orta	45 — 48.8	8 — 23.6	290	125	1.65	1.12
4	Orta	45 — 50.6	8 — 23.5	290	125	1.63	1.11
5	Mergozzo	45 — 57.3	8 — 27.7	196	73	1.48 ^a	0.99
6	Maggiore	45 — 49.4	8 — 35.5	194	120	1.53	1.02
7	Maggiore	45 — 51.9	8 — 34.3	194	260	1.89	1.28
8	Maggiore	45 — 56.2	8 — 36.9	194	343	1.38	0.91
9	Maggiore	45 — 55.3	8 — 28.4	194	128	1.59	1.06
10	Maggiore	45 — 58.4	8 — 39.8	194	367	1.63	1.09
11	Como	45 — 50.4	9 — 5.4	198	159	1.71	1.16
12	Como	45 — 53.1	9 — 20.9	198	148	1.70	1.16
13	Como	45 — 57.2	9 — 10.6	198	398	1.69	1.14
14	Como	45 — 58.5	9 — 17.1	198	286	1.73 ^a	1.18
15	Como	46 — 2.0	9 — 16.1	198	294	1.46	0.99
16	Como	46 — 6.1	9 — 17.9	198	220	1.56	1.04
17	Como	46 — 8.1	9 — 19.5	198	179	1.45	0.97
18	Como	45 — 52.2	9 — 8.5	198	289	1.50	1.00
19	Iseo	45 — 42.5	10 — 4.8	186	245	1.72 ^a	1.17
20	Iseo	45 — 45.7	10 — 3.4	186	105	1.73	1.18
21	Garda	45 — 32.6	10 — 36.5	65	163	1.83	1.24
22	Garda	45 — 36.1	10 — 38.4	65	158	1.87	1.27
23	Garda	45 — 39.1	10 — 40.5	65	243	1.91	1.30
24	Garda	45 — 41.3	10 — 42.8	65	343	1.79	1.22
25	Garda	45 — 44.2	10 — 46.1	65	338	1.69	1.13
26	Garda	45 — 47.1	10 — 48.1	65	332	1.52	1.02
27	Collereto (Ivrea), B_0	45 — 26.3	7 — 48.3	250	100	1.09	0.71
28	Chezalpet, B_0	45 — 43.6	4 — 53.4	657	100	1.95	1.35
29	Monte Bianco, TU	45 — 51.0	6 — 52.7	1300	—	1.99	1.39

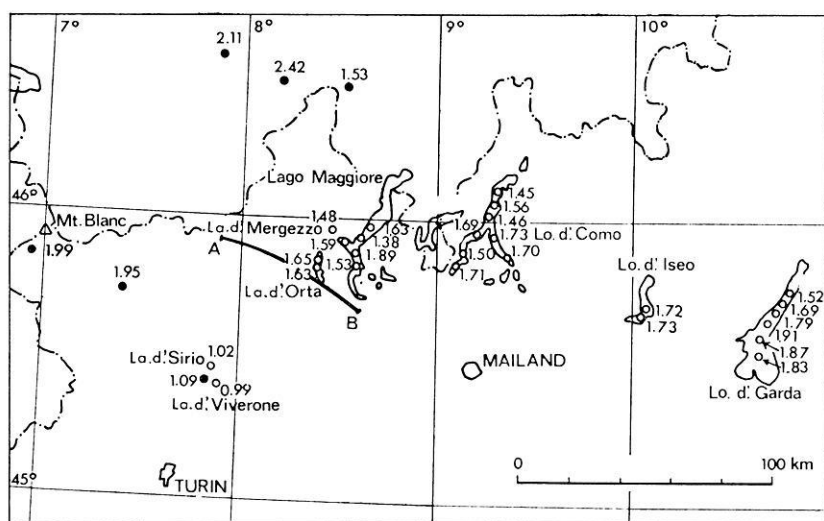


Fig. 1. Heat flow distribution in northern Italy and Switzerland in $\mu\text{cal cm}^{-2}\text{s}^{-1}$. The town Ivrea is near La. d. Sirio. — • drill hole and tunnel values, o lake values, AB seismic profile using a fan array

The correction for these lakes was calculated using a mean annual temperature wave (Haenel, 1970, 1971). Included in Table 1 are values obtained in two drill holes (Colleretto, Ivrea and Chezallet, Aosta) and also in the Monte Bianco-tunnel (Bossolasco and Palau, 1967) (Fig. 1).

The effect of uplift and denudation of the alps was calculated as proposed by Haenel (1973). No sedimentation rates necessary for the calculation of the uplift have yet been published for the area studied. A mean extrapolated sedimentation rate of 0.5 mm yr^{-1} (Haenel, 1973; Fig. 1) was assumed.

The mean of all heat flow values is $\bar{q} = 1.59 \mu\text{cal cm}^{-2}\text{s}^{-1}$ and, after correction for uplift and denudation, $\bar{q}_k = 1.07 \mu\text{cal cm}^{-2}\text{s}^{-1}$. The values for Austria are $\bar{q} = 1.99 \mu\text{cal cm}^{-2}\text{s}^{-1}$ and $\bar{q}_k = 1.39 \mu\text{cal cm}^{-2}\text{s}^{-1}$, respectively. There is an increase of the heat flow in the Alps from west to east. A maximum is reached in the Hungarian basin in which $\bar{q} = 2.46 \mu\text{cal cm}^{-2}\text{s}^{-1}$ is observed.

3. Heat Flow Maps

The maps take into account about 650 heat flow values from points in 14 countries, the Atlantic Ocean, Black Sea, Mediterranean Sea and the Norwegian Sea. Their means are shown in Table 2. A trend analysis was used to calculate the heat flow contour maps (Haenel, 1971). The best-fit surface is of seventh order which was checked by means of a statistical

Table 2. References of the heat flow values used for the trend analysis, and the mean heat flow values for each country

Territory	Number of values	Mean heat flow ($\mu\text{cal cm}^{-2}\text{s}^{-1}$)	Standard deviation ($\mu\text{cal cm}^{-2}\text{s}^{-1}$)	Authors
Austria	30	1.99	0.43	Haenel (1973)
Czechoslovakia	48	1.70	0.39	Cermak (1968)
Finland	5	0.90	0.22	Puranen <i>et al.</i> (1968)
France	8	2.34	0.74	Hentinger and Jolivet
without Soutz	7	2.12	0.36	(1970), Kappelmeyer (1967)
German Democratic Republic	87	1.62	0.37	Becker and Meincke (1968), Meincke, Hurtig and Weiner (1967), Schössler and Schwarzlose (1959)
German Federal Republic	57	1.76	0.46	Creutzburg (1964,
without Landau	53	1.67	0.30	Hüchel and Kappelmeyer (1966), Haenel (1971, 1973)
Great Britain	32	1.53	0.56	see Lee and Uyeda (1965)
Hungary	11	2.46	0.36	Boldizar (1965, 1966)

Italy, Northern part	29	1.61	0.26	This work
Italy, Southern part	10	1.23	0.52	Mongelli and Riccetti (1970), Loddo <i>et al.</i> (1973)
Norway	25	0.96	0.21	Haenel <i>et al.</i> (1974)
Poland	12	1.15	0.29	Plewa (1966), Majorowicz (1973)
Soviet Union (European part)	202	1.48	0.50	Lubimova (1966), Lubimova and Feldman (1970)
Switzerland	4	1.90	0.43	Clark and Niblett (1957), one heat flow value measured by the author in 1973
Atlantic ocean around British Isles	5	1.00	0.38	see Lee (1965)
Black Sea	7	0.91	0.41	Lubimova (1966)
Mediterranean Sea, Western part	25	2.28	1.01	Erickson (1970)
Mediterranean Sea, Eastern part	40	0.86	0.46	Erickson (1970), Haenel (1972) Lavenia (1966)
Norwegian Sea	7	1.44	0.44	Haenel (1973)
Europe	644	1.55	0.58	

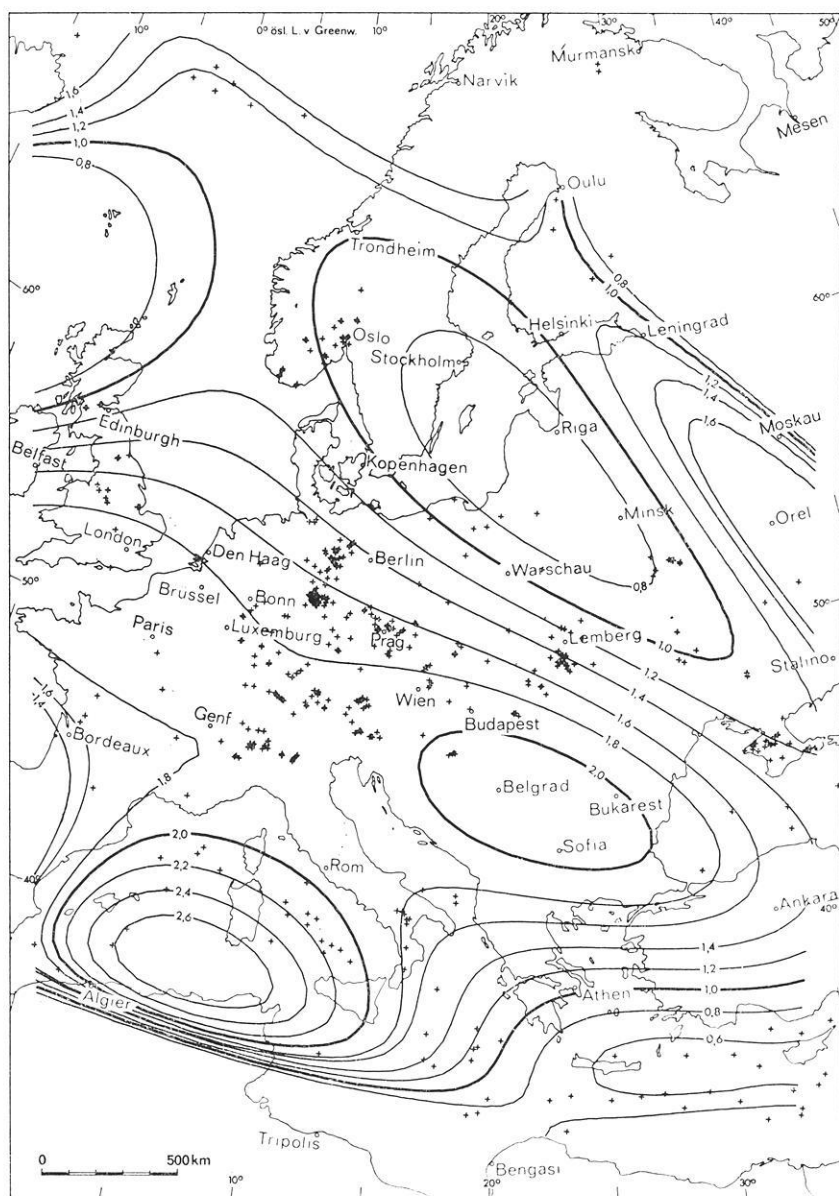


Fig. 2. Distribution of heat flow values and isolines of the trend analysis of 7th order in $\mu\text{cal cm}^{-2}\text{s}^{-1}$, considering only topographic corrections

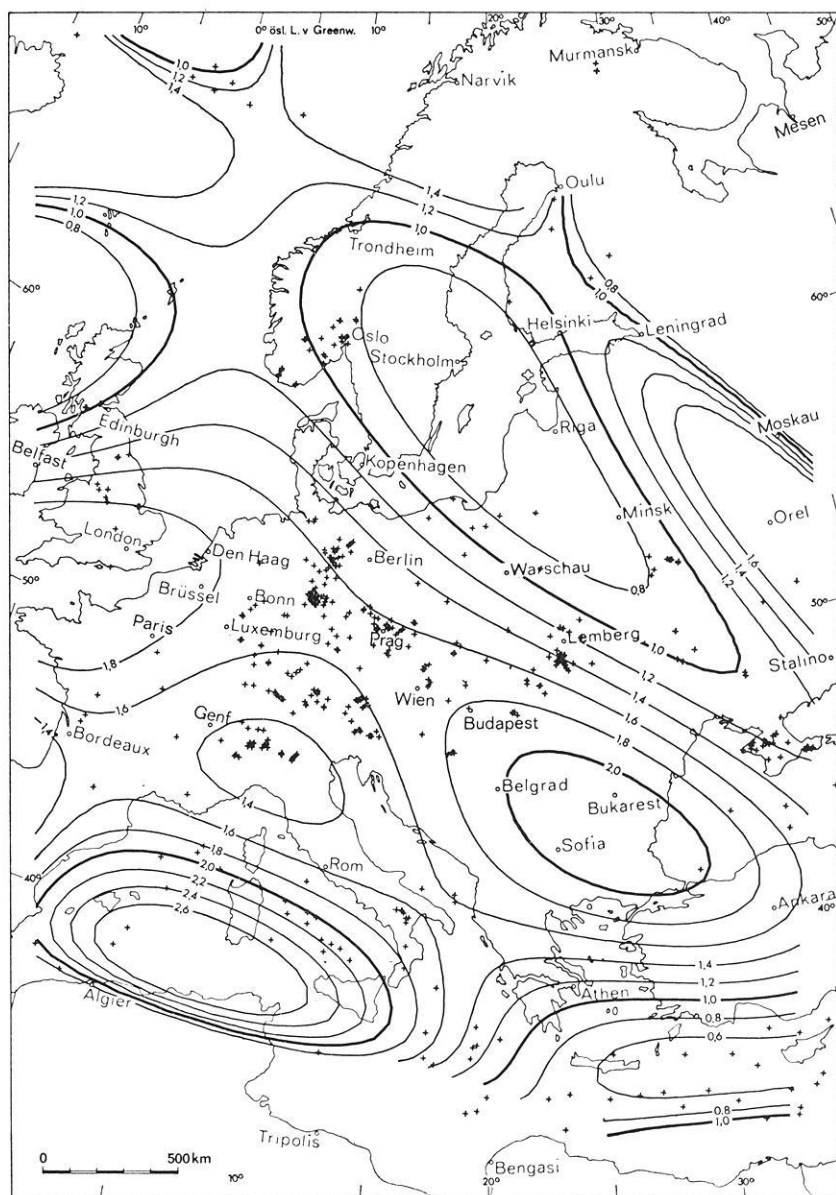


Fig. 3. Distribution of heat flow values and isolines of the trend analysis of 7th order in $\mu\text{cal cm}^{-2}\text{s}^{-1}$ after correction for uplift and denudation of the Alps

test method. E. Mundry¹ kindly provided the relevant computer programmes. Figs. 2 and 3 show the results of the trend analysis.

Both figures show positive and negative heat flow anomalies. It must be born in mind that the polynomial representations near the margins frequently show steep gradients which are not real. Overmore, anomalies appear often there, where only few data points exist (Haenel, 1971).

In the north the values are relatively low, and in the south there are positive as well as negative heat flow anomalies. The central portion of Fig. 2 shows a "threshold" anomaly running northwest-southeast with a maximum in the Hungarian basin. In Fig. 3 there are two maxima and one minimum in this region.

Remarkably the positive Rhinegraben anomaly (Haenel, 1971, 1973) and the negative Ivrea anomaly (see Table 1) are not recognized in the trend analysis. Presumably both anomalies are of local importance in comparison with Europe as a whole.

4. Discussion of Heat Flow Anomalies

Northern Anomaly

In the northern part of Figs. 2 and 3 the extended negative anomaly in the region of Sweden, the Baltic Sea, Poland, and the Soviet Union is well established by many measured heat flow values of $0.8\text{--}1.0 \mu\text{cal cm}^{-2}\text{s}^{-1}$ which are typical for the Precambrian shield and Paleo-Europe (Puranen *et al.*, 1968; Majorowicz, 1973).

Threshold Anomaly (Including the Hungarian and Ivrea Anomaly)

The threshold anomaly is dominant in the central portion of Fig. 2 and Fig. 3, and approximately follows the structure of the Bretagne, the Alps, and the Dinarides. However, in the western and eastern parts of this anomaly only few measurements exist.

The positive anomaly (Hungarian anomaly) south of Budapest in Figs. 2 and 3 might possibly not be as extensive as shown since it is based on only 4 heat flow values. If measurements were available for the Belgrade, Sofia, and Bucharest region, this anomaly might disappear in trend surfaces up to the order of about 7 and would obviously then have only local importance as does the Rhinegraben anomaly. It is possible that the Hungarian anomaly could be interpreted assuming a granitic layer instead of sediments, gneisses, etc. just as in the case of the Rhinegraben anomaly (Haenel, 1971).

In Fig. 3, which eliminates the effect of uplift and denudation, there is a negative heat flow anomaly in the western Alps and Po Plain. This

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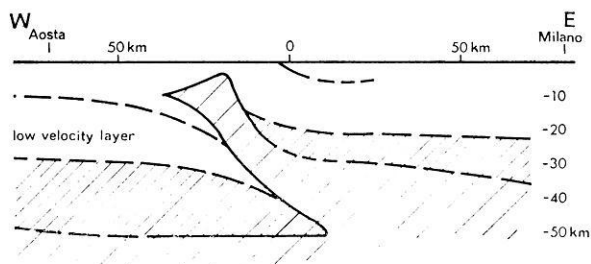


Fig. 4. Ivrea-body after Berckhemer (1968), Giese *et al.* (1967, 1970); see also seismic profile AB in Fig. 1.

□ acid material ▨ basic material ▤ ultrabasic material

anomaly may correspond to a seismic and gravitational anomaly in the surroundings of Ivrea (Berckhemer, 1968; Kaminski and Menzel, 1968). Intrusion of ultrabasic rocks of the Ivrea body began about 200–400 mill. years ago (Graeser and Hunziker, 1968; Jaeger *et al.*, 1960, 1967), and they have perhaps been uplifted to their present location by alpine tectonic processes.

The variable temperature field in the neighborhood of the Ivrea body during the uplift process can be calculated with the non-stationary equation of heat conduction with an advective term:

$$\frac{\partial T}{\partial t} = \frac{\lambda}{\rho c} \cdot \nabla^2 T + \frac{H}{\rho c} + \vec{v} \text{grad } T \quad (1)$$

with:

T = required temperature ($^{\circ}\text{C}$)
 t = time (s)
 λ = thermal conductivity, here $5 \cdot 10^{-3} \text{ cal cm}^{-1}\text{s}^{-1} \text{ deg}^{-1}$
 ρ = rock density, here 2.9 g cm^{-3}
 c = specific heat, here $0.25 \text{ cal g}^{-1}\text{deg}^{-1}$
 H = heat production ($\text{cal cm}^{-3}\text{s}^{-1}$), see Haenel (1971, 1973)
 v = intrusion velocity (cm s^{-1})

For application of Eq. (1) the derivations are replaced by finite differences and the calculation is performed with a high-speed digital computer (Miner and Toksöz, 1970; Mundry, 1970; Peaceman and Rachford, 1955).

The Ivrea body according to Giese *et al.* (1967, 1970) is shown in Fig. 4.

For the time $t=0$ we assume homogeneous crust conditions (up to 30 km depth acid material, up to 50 km basic material, gradient $\sim 3.5^{\circ}\text{C}/100 \text{ m}$). Afterwards the Ivrea body starts to rise with an uplift rate of 1 cm yr^{-1} or 10 cm yr^{-1} resp. (values similar to the seafloor spreading rate (Le Pichon, 1968; Wilson, 1973)). As the uplifted body reaches the surface (see Fig. 4) the rise is assumed to be completed. The calculation is continued.

After about 100 ± 20 mill. years the temperature conditions become stationary. This time span does not exceed the above mentioned rock ages. Therefore today we have stationary conditions with respect to the uplift of the Ivrea body.

West of the Ivrea body the mean heat flow is $q \approx 2.0 \mu\text{cal cm}^{-2}\text{s}^{-1}$. This points to likely temperatures of $600\text{--}800^\circ\text{C}$ in the range of the crustal low velocity layer (10–28 km depth) and therefore the material might be partly or completely molten (see Haenel (1973), Fig. 5).

Detailed temperature investigations for the Ivrea region will be presented in an upcoming paper.

If the heat flow values measured above the Ivrea region are corrected for uplift and denudation, the temperatures at the depth of the low velocity layer are approximately 400°C and therefore too low to explain the low velocity by partial melting. However, there are time dependent limits to the resolution of heat flow values measured at the earth's surface. If there would be temperatures of 700°C or more at 20 km depth then it is possible that the heat may not yet have reached the earth's surface. The time required for the heat to reach the surface can be calculated using the formula (Uyeda and Horai, 1964):

$$\Delta q = \frac{\lambda \Delta T}{t} \left[1 + 2 \sum_{n=1}^{n=\infty} (-1)^n \exp \left(-\frac{\kappa \pi^2 n^2 \cdot t}{t^2} \right) \right] \quad (2)$$

with:

Δq = even measurable heat flow, say $0.1 \text{ cal cm}^{-2}\text{s}^{-1}$

λ = $5 \cdot 10^{-3} \text{ cal cm}^{-1}\text{s}^{-1}\text{deg}^{-1}$

ΔT = sudden temperature rise at $t=0$, about 300°C

z = depth of temperature rise, 20 km

κ = thermal diffusivity, here $1 \cdot 10^{-2} \text{ cm}^2\text{s}^{-1}$

t = time elapsed since beginning of the sudden temperature rise

For these values we calculate a time of about 1 mill. years. Therefore, if 1 mill. years ago at 20 km depth a sudden temperature rise of 300°C occurred such that the total temperature was 600°C or more, the additional heat flow cannot be measured today at the earth's surface, especially if the measuring accuracy is not better than $0.1 \mu\text{cal cm}^{-2}\text{s}^{-1}$.

Western Mediterranean Sea Anomaly

The distribution of the heat flow measurements and a lack of values for northern Africa has given a positive anomaly, which lies southwest from the actual positive heat flow anomaly in the Tyrrhenian Sea. The seismic results (Fahlquist and Hersey, 1969; Hinz, 1972; Hirschleber *et al.*, 1972)

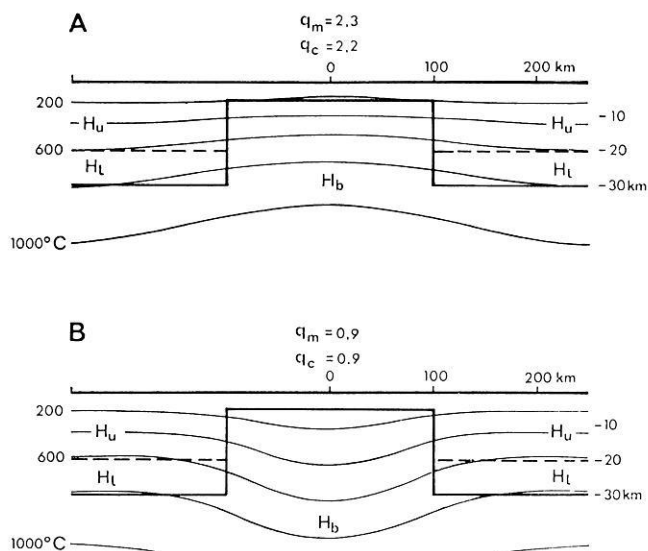


Fig. 5. A. Mediterranean Sea-model (west) with isotherms after 4.5 mill. years. B. Mediterranean Sea-model (east) with isotherms after 15 mill. years. q_m = mean of measured heat flow (see Table 2) in $\mu\text{cal cm}^{-2}\text{s}^{-1}$. q_c = calculated heat flow in $\mu\text{cal cm}^{-2}\text{s}^{-1}$. H_u = heat production for acid material = $0.35 \cdot 10^{-12} \text{ cal cm}^{-3}\text{s}^{-1}$. H_L = heat production for basaltic material = $0.16 \cdot 10^{-12} \text{ cal cm}^{-3}\text{s}^{-1}$. H_b = heat production for ultrabasic material = 0

and the gravity investigations (De Bruyn, 1955) suggest for the region west of Sardinia and in the Tyrrhenian Sea an intrusion of ultrabasic material similar to the Ivrea body (Berry *et al.*, 1969).

However, the results allow only a simple geothermal model (Fig. 5 A). Assumed is the presence of an intrusive body 200 km wide which rose at time $t=0$ from about 50 km depth (temperature are approximately 1000°C there) with the velocity of 1 cm yr⁻¹ and 10 cm yr⁻¹, respectively. Furthermore it is taken $q=1.6 \mu\text{cal cm}^{-2}\text{s}^{-1}$, $\lambda=5 \cdot 10^{-3} \text{ cal cm}^{-1}\text{s}^{-1}\text{deg}^{-1}$, $\rho=2.9 \text{ g cm}^{-3}$, $c=0.25 \text{ cal g}^{-1}\text{deg}^{-1}$, a heat production as indicated Fig. 5 and a grid system with $\Delta x=\Delta z=5 \text{ km}$. The intrusion is finished after 2.5 mill. years and 0.25 mill. years, respectively.

We find that above the center of the intrusion body for $v=10 \text{ cm yr}^{-1}$ after 4.5 mill. years the heat flow is $q_c=2.2 \mu\text{cal cm}^{-2}\text{s}^{-1}$ (see Fig. 5 A) and for $v=1 \text{ cm yr}^{-1}$ after 6 mill. years $q_c=2.0 \text{ cal cm}^{-2}\text{s}^{-1}$.

Eastern Mediterranean Sea Anomaly

Because of insufficient geophysical results we can only apply the same model used for the western Mediterranean Sea. If we continue the above calculation, the nearly stationary condition with $q_c=0.7 \mu\text{cal cm}^{-2}\text{s}^{-1}$

would be achieved after about 15 mill. years (see Fig. 5B) for $v = 10 \text{ cm yr}^{-1}$ and 20 mill. years for 1 cm yr^{-1} , respectively. According to Vine *et al.* (1973) the uplifted Troodos igneous massiv on Cyprus has an age of about 76 mill. years. This does not contradict the ages derived from the geothermal model.

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References

- Becker, D., Meineke, W.: Der Wärmefluß zwischen Harz und Priegnitz. *Z. Angew. Geol.* 14, 291–297, 1968
- Berckhemer, H.: Topographie des Ivrea-Körpers, abgeleitet aus seismischen und gravimetrischen Daten. *Schweiz. Mineral. Petrog. Mitt.* 48, 235–246, 1968
- Berry, M. J., Knopoff, L., Mueller, St.: The low-velocity channel of the upper mantle under the Mediterranean Basin. *Rapp. et Proces-Verbaux des Reunions, XIX*, F4, 669–670, 1969
- Bossolasco, M., Palau, C.: Il flusso geotermico sotto il Monte Bianco. *Geofis. Meteor.* 14, 135–138, 1967
- Birch, F.: Elasticity of igneous rocks at high temperatures and pressures. *Bull. Geol. Soc. Am.* 54, 263–286, 1943
- Birch, F.: Interpretation of the seismic structure of the crust in the light of experimental studies of wave velocities in rocks. In: *Contributions in Geophysics in Honor of Beno Gutenberg*, Vol. 1, ed. H. Benioff *et al.*, 158–170, London: Pergamon Press 1958
- Birch, F.: Investigations of the earth's crust. *International Union of Geodesy and Geophysics*, Monograph No. 22 M. Bath ed., 22–25, IUGG, Paris, 1962
- Cermak, V.: Der Wärmefluß in der CSSR und sein Zusammenhang mit Tiefenstrukturen. *Freiberger Forschungshefte C* 238, 25–32, 1968
- Clark, S. P., Jr., Niblett, E. R.: Terrestrial heat flow in the Swiss Alps. *Month. Not Roy. Astr. Soc., Geophys. Suppl.* 7, 176–195, 1957
- Creutzburg, H.: Untersuchungen über den Wärmestrom der Erde in Westdeutschland. *Kali u. Steinsalz* 4, 73–108, 1964
- De Bruyn, J. W.: Isogram maps of Europe and North Africa. *Geophys. Prospecting* 3, 1–14, 1955
- Fahlquist, D. A., Hersey, J. B.: Seismic refraction measurements in the western Mediterranean Sea. *Bull. Inst. Oceanogr. Monaco*, 70 (Nr. 1386), 1–52, 1969
- Fielitz, K.: Untersuchungen zur Temperaturabhängigkeit von Kompressions- und Scherwellengeschwindigkeiten in Gesteinen unter erhöhtem Druck. *Diss. Univ. Clausthal-Zellerfeld*, 1971

- Giese, P., Prodehl, C., Behnke, C.: Ergebnisse refraktionsseismischer Messungen 1965 zwischen dem Französischen Zentralmassiv und den Westalpen. Z. Geophys. 33, 215–261, 1967
- Giese, P., Günther, K., Reutter, K. J.: Vergleichende geologische und geophysikalische Betrachtungen der Westalpen und des Nordappennins. Z. deutsch. geol. Ges., 120, 151–195, 1970
- Graeser, S. J., Hunziker, C.: Rb–Sr- und Pb–Isotopen-Bestimmungen an Gesteinen und Mineralen der Ivrea-Zone. Schweiz. Mineral. Petrogr. Mitt. 48, 189–204, 1968
- Haenel, R.: A new method for the determination of the heat flow in lakes. Z. Geophys. 36, 725–742, 1970
- Haenel, R.: Heat flow measurements and a first heat flow map of Germany. Z. Geophys. 37, 975–992, 1971
- Haenel, R.: Heat flow measurements in the Ionian Sea with a new heat flow probe. Meteor. Forsch.-Ergebnisse, C, 105–108, 1972
- Haenel, R., Zoth, G.: Heat flow measurements in Austria and heat flow maps of Central Europe. Z. Geophys. 39, 425–439, 1973
- Haenel, R.: Heat flow measurements in the Norwegian Sea. — Meteor. Forsch.-Ergebnisse, C, No. 17, 74–78, 1974
- Haenel, R., Grönle, G., Heier, K. S.: Terrestrial heat flow determination from lakes in Southern Norway. Norwegian J. Geol., in press
- Hentiger, R., Jolivet, J.: Nouvelles Déterminations du Flux Géothermique en France. Tectonophysics, 10, 127–146, 1970
- Hinz, K.: Results of seismic refraction investigations (Project Anna) in the western Mediterranean Sea, south and north of the island of Mallorca. Bull. Centre Rech. Pau-SNPA 6, 405–426, 1972
- Hirschleber, H., Rudloff, R., Snoek, M.: Preliminary results of seismic measurements in the Gulf of Lion. Bull. Centre Rech. Pau — SNPA, 6, 395–402, 1972
- Hughes, D. S., Maurette, C.: Variation of elastic wave velocities in basic igneous rocks with pressure and temperature. Geophysics 22, 23–31, 1957
- Hughes, D. S., Maurette, C.: Détermination des vitesses d'onde élastique dans diverses roches en fonction de la pression et de la température. Rev. Inst. Franc. Pétrole 12, 730–752, 1957
- Hückel, B., Kappelmeyer, O.: Geothermische Untersuchungen im Saarkarbon. Z. dt. geol. Ges., 117, 280–311, 1966
- Hurtig, E.: Der Wärmefluß in Mitteleuropa. Z. geol. Wiss. 1, 461–466, 1973
- Jäger, E., Faul, H.: Altersbestimmungen an einigen Schweizer Gesteinen und dem Granit von Baveno. Schweiz. Mineral. Petrogr. Mitt. 40, 10–12, 1960
- Jäger, E., Faul, H.: Rb–Sr-Alter an Gesteinsglimmern der Schweizer Alpen. Schweiz. Mineral. Petrogr. Mitt. 41, 255–272, 1961
- Kaminski, W., Menzel, H.: Zur Deutung der Schwereanomalie des Ivrea-Körpers. Schweiz. Mineral. Petrogr. Mitt., 48, 255–260, 1968
- Kappelmeyer, O.: The geothermal field of the upper rhinegraben. The Rhinegraben Progress Report 1967, Abh. geol. Landesamt Baden-Württemberg 6, 101–103, 1967
- Lavenia, A.: Prime misure sperimentali di flusso termico in mare. Boll. Geophys. Teor. Appl. VIII (No 27), 40–55, 1966
- Lee, H. K., Uyeda, S.: Review of heat flow data. In: Terrestrial heat flow, Am. Geophys. Union, Geophys. Monogr. No. 8, 87–190, 1965
- Le Pichon, X.: Sea-floor spreading and continental drift. J. Geophys. Res. 73, 3661–3697, 1968

- Loddo, M., Mongelli, F., Roda, C.: Heat flow in Calabria, Italy. *Nature Phys. Sci.* 244, (136), 91–92, 1973
- Lubimova, E. A.: On construction of temperature profiles for the earth's crust and reduction of seismic ambiguity. *J. Phys. Earth* 14, 27–36, 1966
- Lubimova, E. A., Feldman, I. S.: Heat flow, temperature, and electrical conductivity of the crust and upper month in the U.S.S.R. *Tectonophysics* 10, 245–281, 1970
- Majorowicz, J. A.: Heat flow data from Poland. *Nature (Phys. Sci.)* 241, 16–17, 1973
- Meincke, W., Hurtig, E., Weiner, J.: Temperaturverteilung, Wärmeleitfähigkeit und Wärmefluß im Thüringer Becken. *Geophys. Geol.* 11, 40–71, 1967
- Miner, J. W., Toksöz, M. N.: Thermal regime of a downgoing slab and new global tectonics. *J. Geophys. Res.* 75, 1397–1419, 1970
- Mongelli, F., Riccetti, G.: The earth's crust and heat flow in the Fossa Brandanica, Southern Italy, *Tectonophysics* 10, 103–125, 1970
- Mundry, E.: Mathematical estimation concerning the cooling of a magmatic intrusive. *Geothermics, Special Issue 2, Part I*, 662–668, Pisa, 1970
- Peaceman, D. W., Rachford, H. H., Jr.: The numerical solution of parabolic and elliptic differential equations. *J. Soc. Ind. Appl. Math.* 3, 28–41, 1955
- Plewa, St.: Regionalny oraz parametrow geotermicznych obszaru polski. *Wydawnictwo Geofizyka i Geologia Naftowa*, 1–88, Krakow, 1966
- Puranen, M., Järvinen, P., Hämäläinen, U., Lektinen, S.: Terrestrial heat flow in Finland. *Geoexploration* 6, 151–162, 1968
- Schössler, K., Schwarzlose, J.: Geophysikalische Wärmeflußmessungen. *Freiberger Forschungshefte C* 75, 1–120, 1959
- Uyeda, S. K., Horai, K.: Terrestrial heat flow in Japan. *J. Geophys. Res.* 69, 2121–2141, 1964
- Vine, F. J., Poster, C. K., Gass, I. G.: Aeromagnetic survey of the Troodos igneous massif, Cyprus. *Nature (Phys. Sci.)* 244, 34–38, 1973
- Wilson, J. T.: Evidence from islands on the spreading of ocean floors. *Nature* 197, 536–538, 1963

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