Zeitschrift: Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie

Band: 59 (1979)

Heft: 1-2

Artikel: Geothermic and radiometric investigations

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DOI: https://doi.org/10.5169/seals-46050

Schweiz. mineral. petrogr. Mitt. 59, 141-148, 1979

Swiss National Committee for the International Geodynamics Project
Working Group 5: Heat Flow and Radioactivity

Geothermic and Radiometric Investigations

Report by *L. Rybach* *)

The present report summarizes the activity of Working Group No. 5 during the period 1971-79. Besides the activities reported below which relate closely to geodynamic problems a number of further sidelines of geothermics and radiometry have been followed up, mainly in view to practical applications: assessment of geothermal potential, underground heat storage, prospecting for uranium mineralisations, radioactive waste disposal. Computer codes as well as experimental techniques developed for these «applied» topics have been subsequently utilised with great benefit in the more «general» projects listed below.

Working Group Members are: Ph. Bodmer, P. Finckh, K.J. Hsü, E. Kissling, M. Parini, L. Rybach, D. Werner (Zurich), T. P. Labhart (Berne), G. Berset **) (Lucerne).

1. SUBSURFACE TEMPERATURES

A reliable data base is necessary for downward extrapolation of near-surface data in order to delineate the temperature field in the earth's crust. Temperature measurements have been performed in all accessible drill-holes, tunnels, shafts etc.: continuous logging as well as bottom-hole measurements (the latter corrected for effects of mud circulation) in drillholes, single-point measurements in the rock face in tunnels and shafts. The results are compiled in a uniform format (KRÜSI et al., 1978).

Computer programs have been developed to account for the effect of surface topography and its evolution on subsurface temperatures (BODMER et al., 1979). The availability of a topographic array, covering whole Switzerland with a distance between mesh points of 250 m, avoids digitizing by hand. In areas like the Swiss Alps where considerable relief exists the effect of topography on subsurface temperatures prevails down to depths $\gtrsim$ 5 km.

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2. HEAT FLOW DETERMINATIONS

Heat flow determinations have been carried out in drillholes, shafts and in lake-bottom sediments. The corrections applied account for topography, uplift/erosion, sedimentation and climatic changes. Special attention was given to the evaluation of suitable sites for heat flow determinations in lake bottom sediments (v. HERZEN et al. 1974, FINCKH 1976, FINCKH & KELTS 1976). The results are discussed in accordance with their geologic-tectonic settings in RYBACH & FINCKH (1979). In the Northern Foreland of the Swiss Alps, especially towards the Upper Rhine Graben, heat flow values up to 100 mW/m^2 have been observed, whereas the Swiss Alps are characterized by generally lower and less uniform heat flow, reflecting the complex present and past geodynamics of this area (RYBACH et al. 1977, WERNER 1977).

In order to summarize on-going geothermal research activities in Europe and to represent the heat flow field on a continental scale the Monograph «Terrestrial Heat Flow in Europe» has been prepared. Due to the manifold geodynamic implications of heat flow this Monograph appears as *«Inter-Union Commission of Geodynamics Scientific Report No. 58»* (ČERMÁK & RYBACH 1979).

3. HEAT PRODUCTION

Abundance and distribution of radiogenic heat sources greatly influence the temperature field in the continental crust (see e.g. RYBACH 1976 a). Experimental techniques (gamma ray spectrometry) have been developed for heat production determination (RYBACH, 1971). Revised heat production constants for the main radioelements uranium, thorium and potassium are given in Table 1.

*Table 1 Revised heat production constants (*RYBACH*, 1976 b)*

Element	*A [cal/g,y] (Birch, 1954)*	*A [cal/g,y] (Rybach, 1976 b)*	*A [W/kg] (Rybach, 1976 b)*
Uranium	0.73	0.718	$9.525 \cdot 10^{-5}$
Thorium	0.20	0.198	$2.561 \cdot 10^{-5}$
Potassium	$276 \cdot 10^{-6}$	$26.2 \cdot 10^{-6}$	$3.477 \cdot 10^{-9}$

Systematic laboratory studies have been carried out in order to assign characteristic heat production values to the main rock types of the Swiss Alps (RYBACH, 1973). Geochemical variation trends (heat production – bulk chemical composition of rocks) are summarized and discussed in RYBACH (1976c).

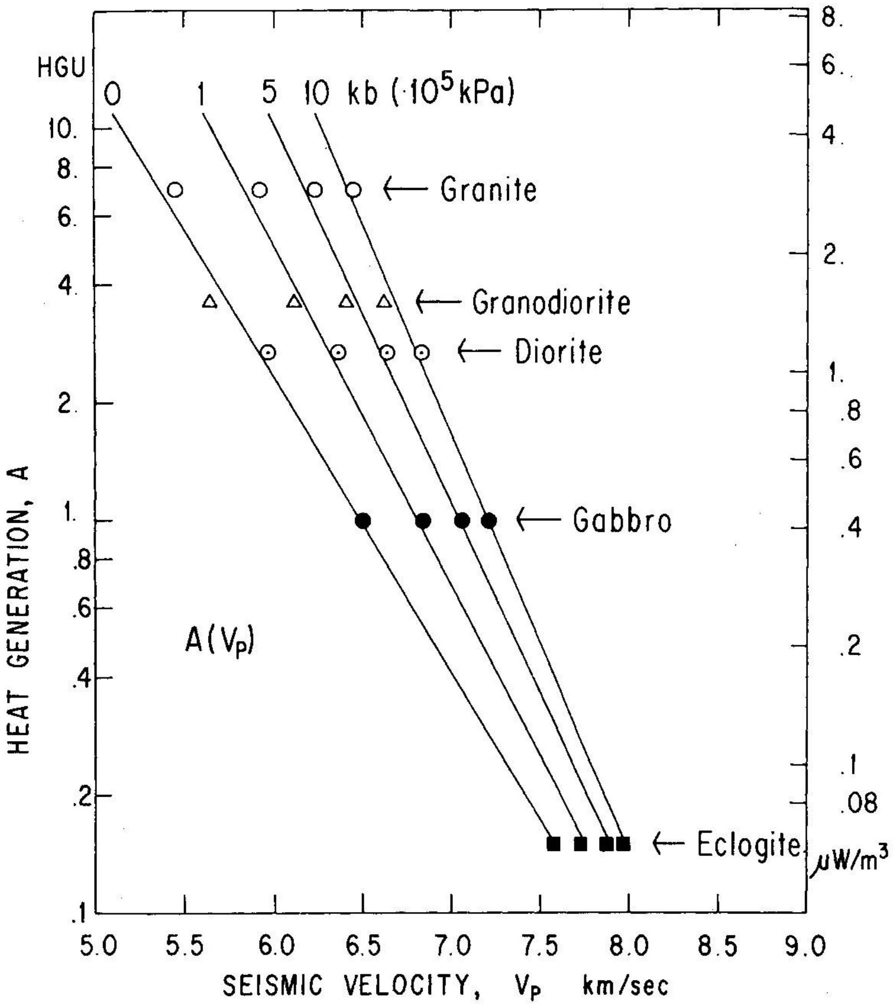

Fig. 1 The seismic velocity – heat production relationship for different pressures (from RYBACH, 1978).

The zonation pattern of heat production A in granitic batholiths (decreasing A towards the center of the body) has been studied in detail in the Rotondo granite (Gotthard massif, Central Alps): vertical decrease of A with depth has been found; the logarithmic decrement (for exponential decrease) is H=8 km (KISSLING et al. 1979).

An empirical relationship between heat production A and compressional wave velocity v_p has been found (RYBACH, 1973; 1976b): in the range characteristic of crustal rocks (5–8 km/sec) A decreases exponentially with increasing v_p: $A(v_p) = a \cdot \exp(-b \cdot v_p)$; where the numerical factors a and b depend on in-situ pressure and temperature (Fig. 1).

4. GEOTHERMICS AND GEODYNAMICS

In order to shed light on the manifold interrelations of geothermics and geodynamics basic theoretical investigations have been carried out: dynamic modeling of heat conduction in a moving system, interactions between heat and mass transfer (WERNER 1975).

Special studies have been devoted to

a) gravity anomalies in the wake of drifting continents, caused partly by radiogenic heating of the overriding lithosphere (KAHLE & WERNER 1975)
b) cooling history of the Lepontine area (Central Alps), considering time-dependent uplift/erosion (WERNER et al. 1976; see also Fig. 2)
c) the geothermal anomaly of the Upper Rhine Graben: the regional part can be attributed to hot rising mantle material below this continental rift structure (WERNER & FUCHS, 1977; WERNER et al., 1978; KAHLE & WERNER, 1979; WERNER & KAHLE, 1979, cf. Fig. 3), whereas local anomalies like the Landau anomaly are interpreted as hydrothermic effects (WERNER & PARINI, in preparation). The anomalous temperature field can explain the observed discrepancy in the gravity anomalies (up to 160 mgal). The velocity and density inversions in the upper crust which are associated with pronounced lateral and vertical temperature gradients are also responsible for the relative vertical motions in the Rhine Graben (MÜLLER & RYBACH, 1974).

5. GEOTHERMAL MAPS

Recent activities in Switzerland focus on the preparation of maps representing the geothermal conditions at depth. This project is sponsored by the Swiss Geophysical Commission and by the Federal Office of Energy. Based on

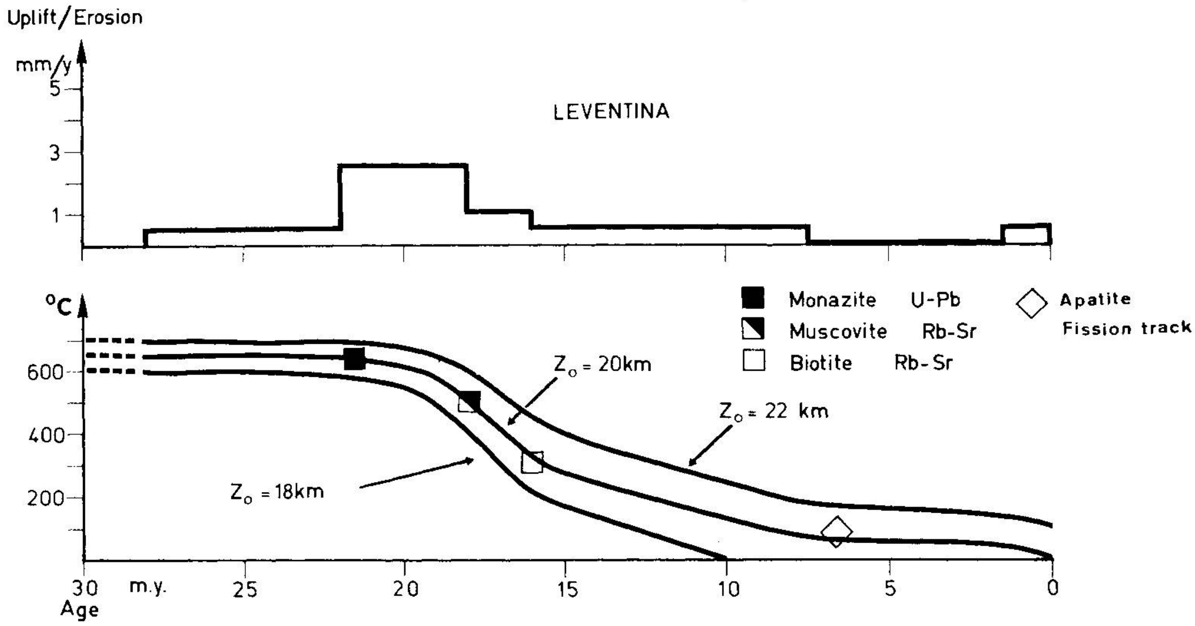

Fig. 2 Time-dependent uplift/erosion in the Lepontine area (upper part of diagram) and corresponding cooling history (lower part). Calculation by D. WERNER, based on data from WERNER et al. (1976) and apatite fission track data from WAGNER et al. (1977). Orogenic activity was strongest 20 mio years ago; quiescent period during the Pliocene.

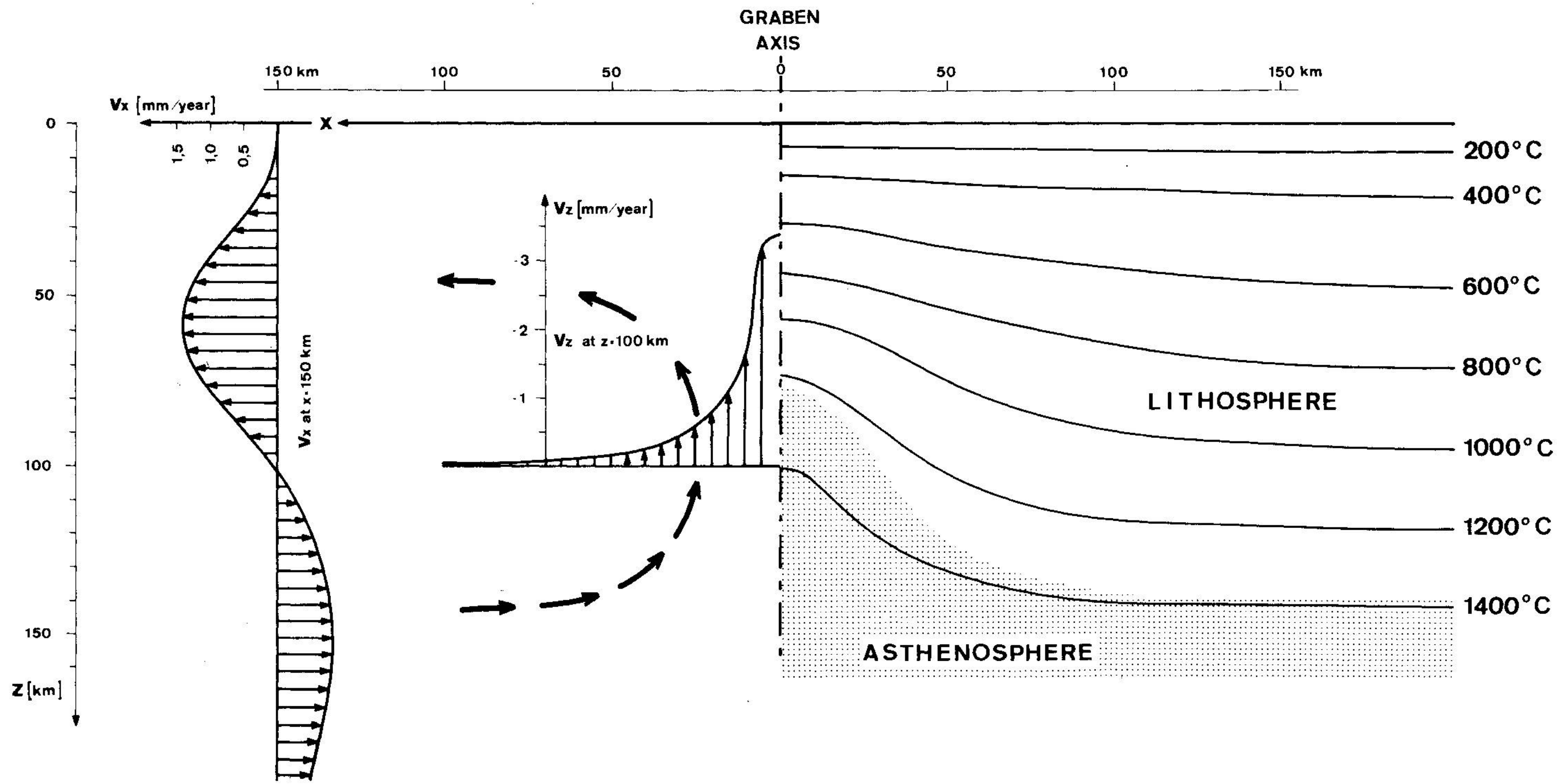

Fig. 3 Model of material and heat transport in the uppermost mantle below the Rhine Graben (from WERNER & KAHLE, 1979)

Left: The velocity field v = (v_x,v_z) for the upwelling mantle material under the graben zone which produces a thermal anomaly;

Right: The temperature field after 45 mio years caused by convection and thermal conduction; a calculated boundary between lithosphere and asthenosphere (stippled area) depending on temperature and pressure is also indicated.

the geothermal data compilation (Krüsi et al., 1978) the temperature field can be mapped in the Northern Foreland (Swiss Molasse Basin and Swiss Jura) with sufficient detail: direct information from 37 deep drillholes with an average depth of 1820 m enables the construction of a geothermal gradient map (Fig. 3). Further maps display the subsurface temperatures at different depths (e.g. $T_{1\,km}$). The geothermal anomaly in the Upper Rhine Graben has been mapped by Werner & Doebl (1974).

6. SYSTEMATIC ROCK RADIOACTIVITY MEASUREMENTS

Systematic radiometric measurements are carried out in alpine tunnels (hydroelectric, pipeline, autoroute tunnels) within the framework of the Swiss Geotechnical Commission. These deep tunnels offer the unique opportunity to study in detail tens of kilometers of unweathered lithologic series and thus give valuable information on the distribution of heat generating radioelements. A first qualitative evaluation of the vast number of single measurements (over 100000) is reported in Labhart & Rybach (1974) and Labhart (1976).

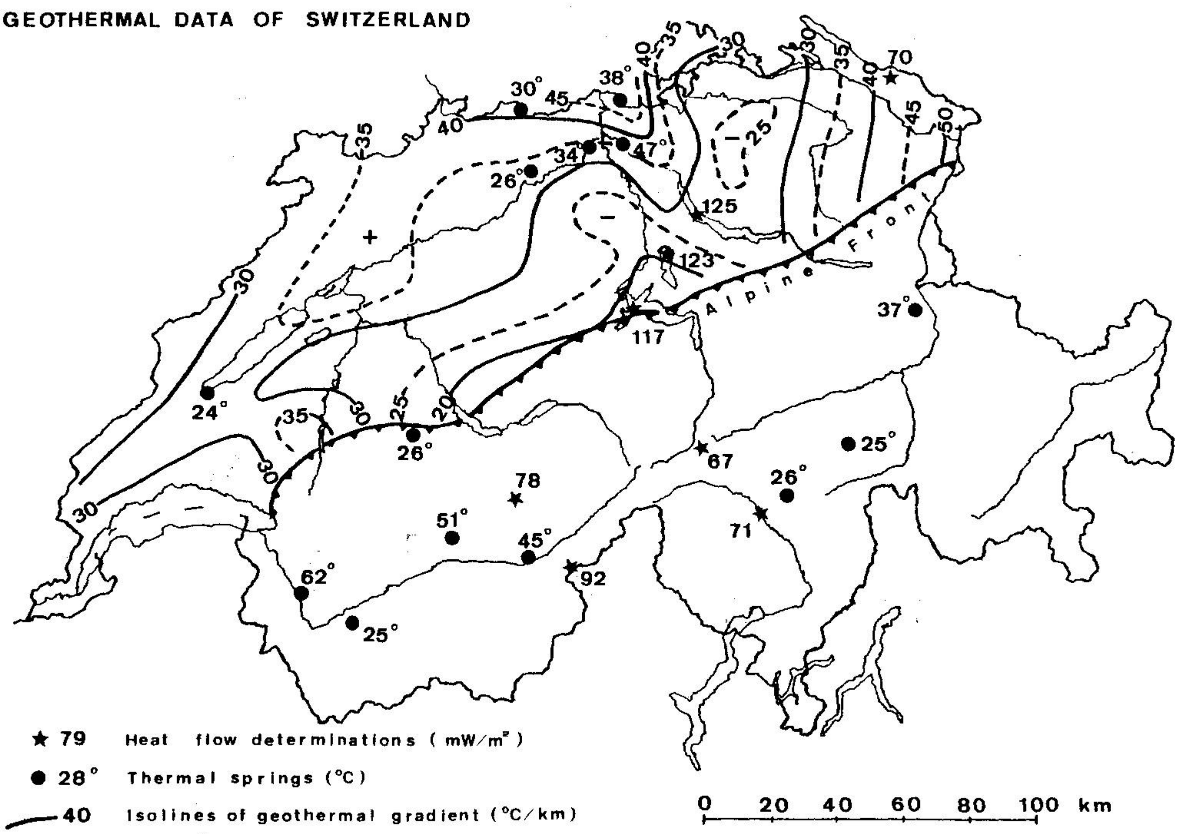

Fig. 4 Geothermal data of Switzerland. Temperature gradient map of the Northern Alpine Foreland after Krüsi et al. (1978), heat flow data from Rybach & Finckh (1979) and thermal springs from Rybach & Jaffé (1976).

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Manuscript received July 23, 1979