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Cooling Models for the Lepontine Area (Central Swiss Alps) *)

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Abstract

Cooling models satisfying petrological, geochronological and geological constraints were calculated for areas in the Lepontine region where extremely rapid cooling is indicated. The calculations show that time dependent uplift rates temporarily as high as 4 to 5 mm/y are necessary to satisfy the constraints. Within the central part of the Lepontine area two different periods can be distinguished, a period of rapid uplift from about 25 to 18 m.y. ago and a period of considerably smaller uplift from about 15 m.y. ago until the present.

Geothermal cooling models for the Lepontine area were calculated on the basis of the following assumptions:

— Mineral reactions indicate that during the Alpine metamorphism temperatures of 600 to 650°C were reached in the central part of the Lepontine area (Blattner, 1965, 1972; Hänny, 1972; Trommsdorff and Evans, 1974; Frey et al., 1974).

— In the zone of high grade metamorphism a depth of burial of about 20 km was reached at the time of prograde metamorphism (Niggli, 1970; E. Wenk, 1970; Hänny, 1972; H. R. Wenk et al., 1974; Thompson, 1976).

— The high temperature period of metamorphism is indicated by the concordant monazite ages varying regionally between 20 to 30 m.y. (Köppel and Grünenfelder, 1975) in agreement with the time indicated by the whole rock strontium isotope homogeneization in a scale of 1 to 10 cm in the V. Bodengo area (Hänny et al., 1975). The occurrence of pre-Alpine monazite ages in the Lepontine area also indicates that the pattern of young concordant monazite ages is related to periods of high temperatures rather than to periods of subsequent cooling. East of V. Maggia granitoid rocks and gneisses such as the granitoid gneisses of V. Tomeo (Cocco gneiss) and N. of Giumaglio contain monazite which yielded ages of more than 200 m.y.,

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some almost concordant between 250 and 270 m.y. (KÖPPEL and GRÜNENFELDER, in preparation), and which thereby strongly contrast with the monazite ages of about 23 m.y. in the surrounding area.

— Rb-Sr muscovite and biotite ages represent cooling ages to about 500° C, respectively 300° C (JÄGER et al., 1967).

— Uplift of the eastern Lepontine area started about 28 m.y. ago as is demonstrated by the onset of the middle Oligocene conglomerates near Chiasso which were deposited contemporaneously with the widespread conglomerates in the northern Molasse foreland (RÖGL et al., 1975; HOCHULI, personal communication).

— We assume that the rate of uplift equals the rate of erosion which is, of course, the case only when the uplifted area has reached a certain height.

— A "best fit" geothermal model was sought which satisfies the above mentioned assumptions. There are two geothermal processes which must be taken into account: (i) motion of material and (ii) heat conduction. The general differential equation of heat transfer in a moving medium is

$$\vec{v}\ \mathrm{grad}\ T + \frac{\partial T}{\partial t} = \kappa \nabla^2 T + \frac{A}{c\rho}. \tag{1}$$

T: temperature field
$\vec{v}$: velocity field (of geodynamic process)
κ: thermal diffusivity (in our model 2.4×10^{-5} km^2/y)
t: time
A: heat generation
$c\rho$: heat capacity × density

It is possible to reduce formula (1) to a more simple one in which only the z-coordinate (depth) occurs:

$$v_z(t)\frac{\partial T(z,t)}{\partial z} + \frac{\partial T(z,t)}{\partial t} = \kappa \frac{\partial^2 T(z,t)}{\partial z^2} + \frac{A(z,t)}{c\rho}. \tag{2}$$

Furthermore the surface condition is:

$$T(o,t) = 0. \tag{3}$$

Using equations (2) and (3) it is assumed that a crustal segment moves up (or down) as a whole block, or, to be exact, as a half space. The simplest model would be given by a crustal segment which rises with a constant uplift/erosion rate $\epsilon = v_z$ (independent of time). In this case a solution of equation (2) can be found by analytical methods (CARSLAW and JAEGER, 1959; CLARK and JÄGER, 1969). The present data require a more flexible method which enables to evaluate a time depending ϵ rate. Therefore our calculations are based on the finite difference method (WERNER, 1975) related to equation (2).

— In the cooling models we assume a steady state initial temperature versus depth distribution (fig. 1).

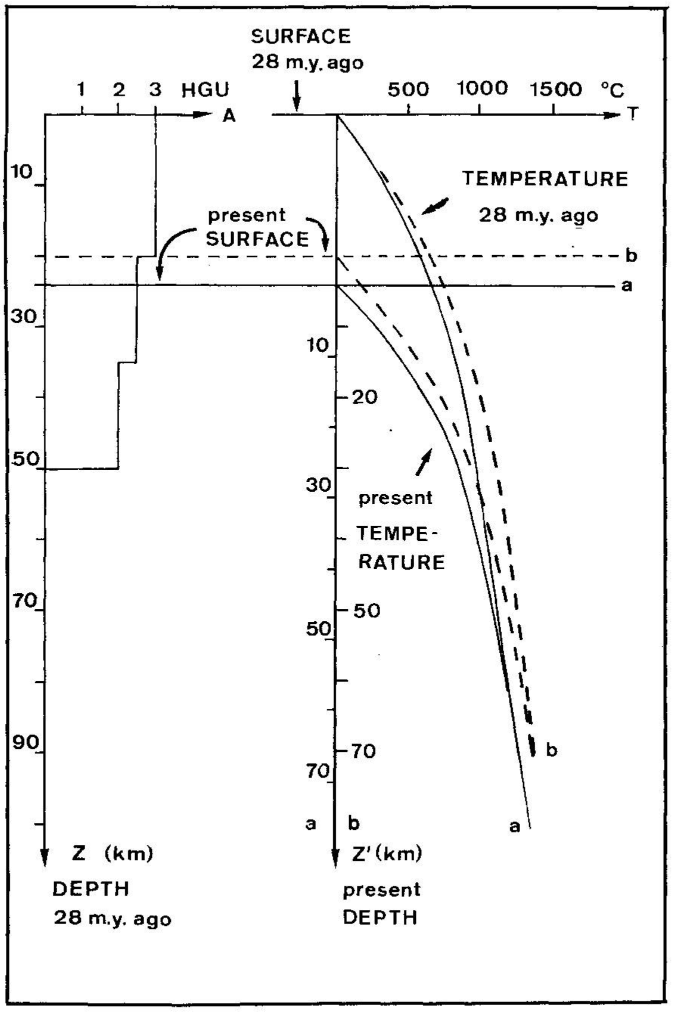

Fig. 1. Temperature and heat sources distribution. Left part: Radioactive heat sources, based on Rybach et al. (1977), 1 HGU = 0.419 $\mu W/m^3$. Right part: Two different initial and present temperatur-depth curves (see text).

At present we have restricted the calculation of models to such areas where the isotopic ages indicate extremely rapid cooling, because the time appeared to be extremely short to cool such large rock masses. From the available data it appears that rapid cooling especially took place in the Bodengo and the Leventina area (fig. 2). Disregarding the analytical uncertainties the age difference between the Rb-Sr muscovite and biotite ages is only about 2 m.y. in the Bodengo-Leventina area and probably about 4 m.y. or more in the Verzasca area. The age difference between monazite and muscovite is a minimum in the Leventina area, 2 to 3 m.y. and slightly higher, 3 to 4 m.y. in the Bodengo and Verzasca regions. Furthermore, rapid cooling is also indicated in

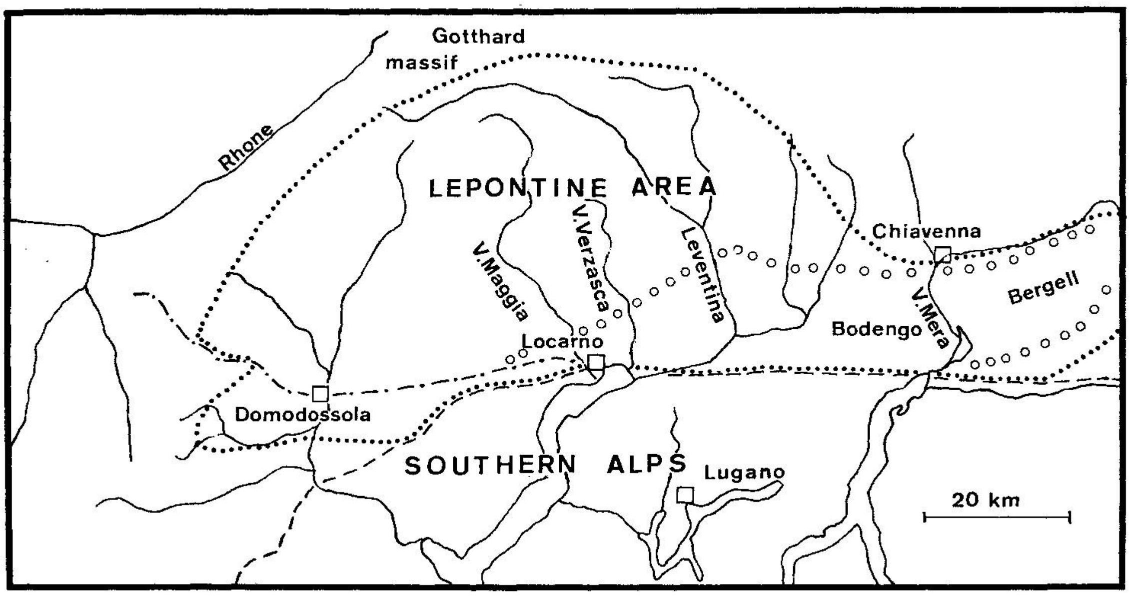

Fig. 2. Sketch map showing the principal locations discussed in the text. Boundary of Alpine amphibolite facies metamorphism ·······, sillimanite zone oooooo. Insubric line ——————, Simplon–Centovalli fault —·—·—.

the Verampio area N of Domodossola where the micas show an age difference of about 2 m.y. (Jäger et al., 1967) and in the eastern part of the Bergell area where monazite and biotite yielded differences of 5 m.y.

Fig. 3 and 4 show the rate of uplift required to satisfy the constraints of cooling and the temperature versus time curves for different critical depths. The calculations are based on the temperature versus depth curve a) of fig. 1. The rapid cooling requires relatively high rates of uplift of up to 4 and 5 mm/y. Uplift rates of this magnitude will cause extremely high surface temperature gradients. It is also obvious that cooling from 500 to 300°C can only take place in rather shallow depths of 7 to 3 km. The calculations show that the temperature versus time curve is very sensitive to the original depth as well as to small changes in the rate of uplift. Similar results (fig. 5, 6) obtained by assuming different initial depths and slightly different initial temperature distributions such as the temperature versus depth curve b) in fig. 1.

It is clear that these extreme cooling rates are restricted to certain areas of the Lepontine region, whereas in other areas, such as the Simplon area or the "root zone", less extreme cooling rates prevailed. Different regions require different uplift histories, for instance, in the eastern Bergell area monazite yielded an age of 30 m.y. (Gulson and Krogh, 1973) and biotite of 25 m.y. (Jäger et al., 1967), the age difference being thus similar to the one of the Bodengo area and the period of rapid uplift is likely to coincide with the period of conglomerate deposition in the Chiasso–Como area (Rögl et al., 1975). It appears that in the South conglomerates equivalent to the upper Miocene

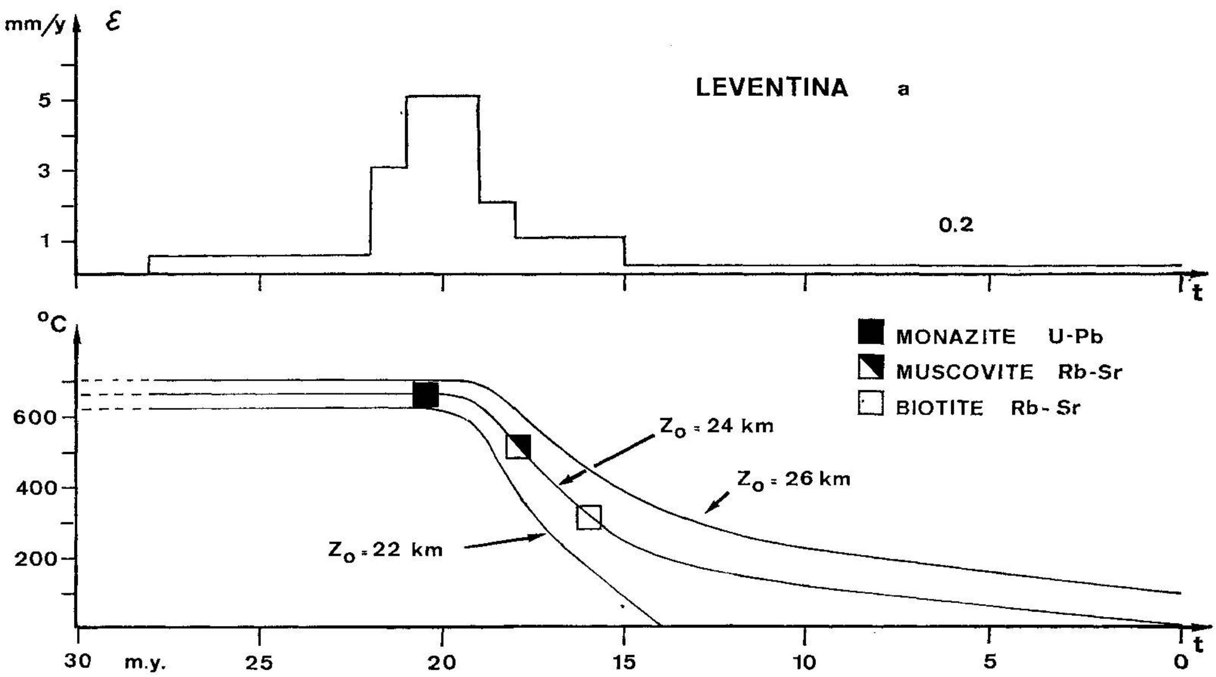

Fig. 3. Results of model calculations for the case "Leventina", according to the curves *a* in Fig. 1. The uplift/erosion history, as shown in the upper part, leads to the cooling curves (lower part). The cooling curve for an original depth of $z_0 = 24$ km satisfies the constraints given by the temperature-age marks.

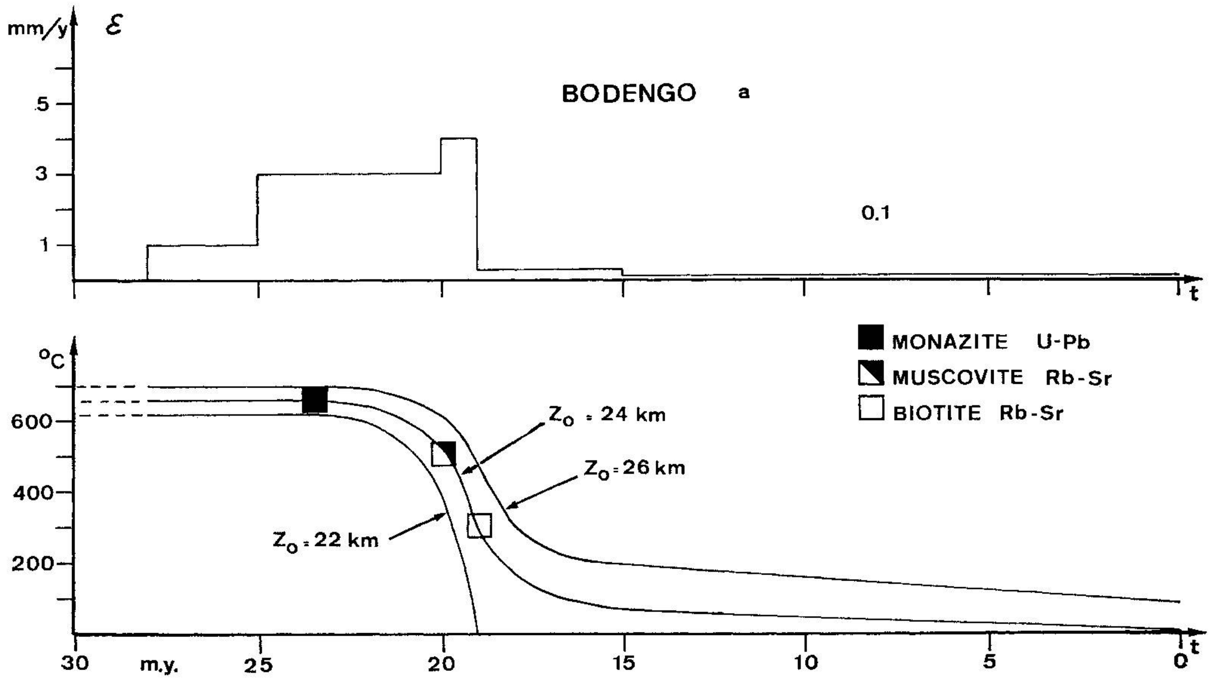

Fig. 4. Results of model calculations for the case "Bodengo", according to the curves *a* in Fig. 1.

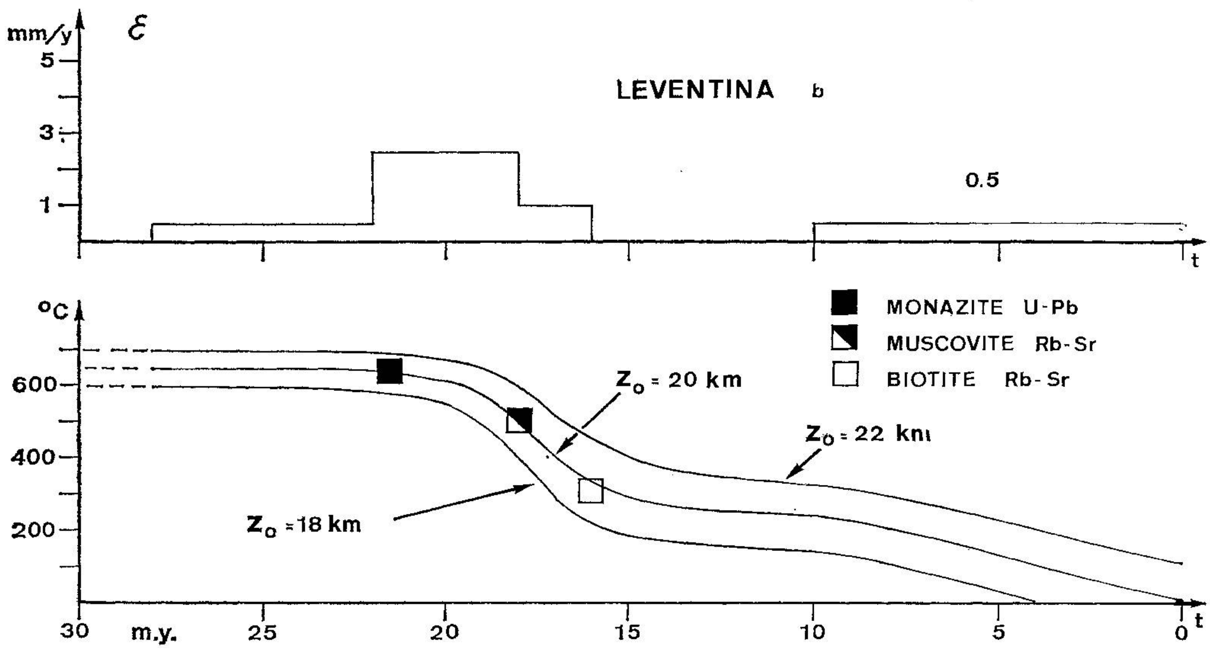

Fig. 5. Results of model calculations for the case "Leventina", according to the curves *b* in Fig. 1.

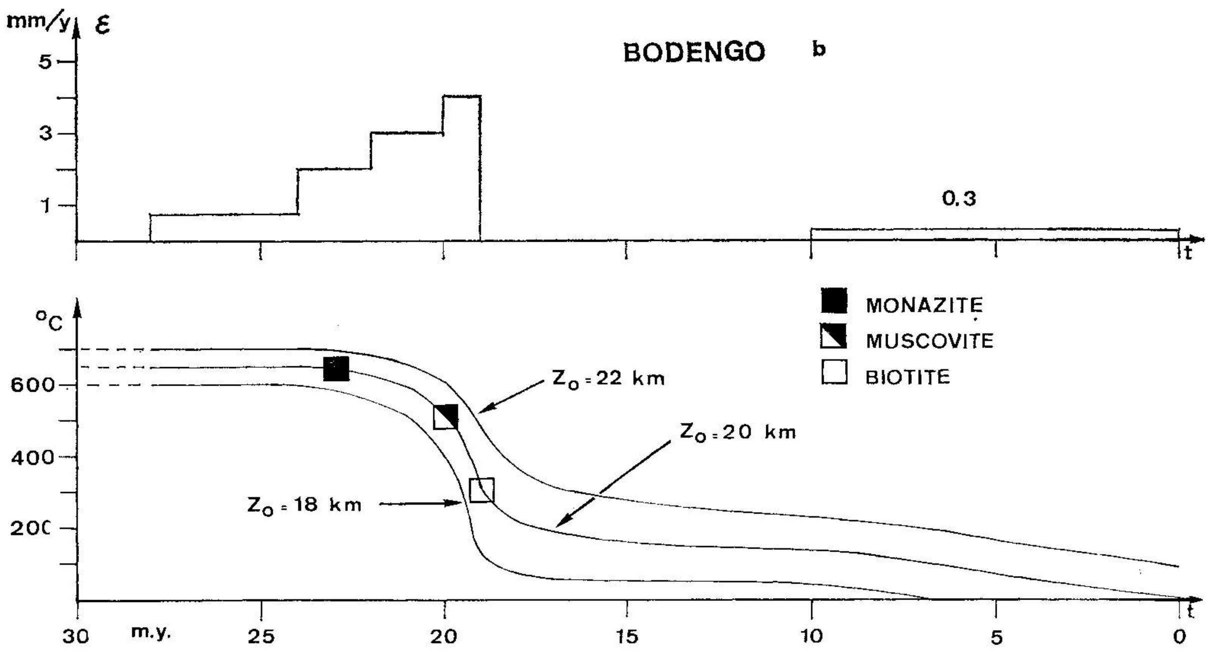

Fig. 6. Results of model calculations for the case "Bodengo", according to the curves *b* in Fig. 1.

conglomerates of the northern foreland basin are absent. The lithology of the sediments in the northern Molasse basin rather reflects the tectonic history of the area North of the Lepontine region than that of the Lepontine area itself.

The main results of our investigations can be summarized as follows:

— The Lepontine area requires a time dependent model of uplift.
— Within the central part of the Lepontine area two different periods can be distinguished, a period of rapid uplift about 25 to 18 m.y. ago and a period of considerably smaller uplift from about 15 m.y. ago until the present.
— The uplift histories of the Leventina and Bodengo areas are similar, however their maximum rate of uplift occurred at different times.

Investigations of dynamic models, including differential mass transport, by means of equation (1) are in progress.

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