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Physical Constants of Alpine Rocks (Density, Porosity, Specific Heat, Thermal Diffusivity and Conductivity) *)

By *Hans-Rudolf Wenk* (Berkeley) **) and *Eduard Wenk* (Basel) ***)

With 3 figures in the text

Abstract. Physical constants of 110 Alpine rocks are given. They include density, heat capacity, porosity, thermal diffusivity (with special regard to the anisotropy in different fabric directions). Most of the samples were collected in the Lepontine area which was subjected to a Tertiary metamorphism.

INTRODUCTION

The Alps belong geologically to the best studied orogens of the world. Detailed mapping established structural units on which, for example, the nappe theory is based. Many mineralogical and petrographical studies have increased the understanding of rock-forming processes. The descriptive work is entering a final stage, filling up the last blank spots; refinement of the earlier work has begun. Although this does not mean that modifications will no longer occur, it means that it is time for another science to enter the field: geophysics has now to propose possible mechanisms in order to quantitatively verify or disprove models developed by field geologists. There is no need to mention how much this has been neglected. In Central Europe geophysicists seem to carefully avoid all contact with geological objects of continental importance. Seismologic research, on tectonics, for instance, is decades behind the times. Characteristic of Alpine geology is a large discrepancy between elaborate and advanced geological investigation and a completely neglected geophysical approach. If

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this had not been so, certain speculations advanced by field geologists could immediately have been ruled out.

In the early days of this century some fundamental work on heat distribution in the Alps was done (NIETHAMMER, 1910) and thermal conductivities of a few specimens were measured (KÖNIGSBERGER and MÜHLBERG, 1911; FRIEDLAENDER, 1912). Recently CLARK and NIBLETT (1956) made a survey on heat flow in Alpine tunnels and calculated a model which is unfortunately based on wrong geological assumptions. We contribute to this quantitative approach in giving physical constants for Alpine rocks on which calculations can be based. In this first part density, specific heat, porosity, thermal diffusivity and conductivity are determined on 110 specimens. Further work on the same specimens will include radiometric determinations and elastic wave velocities. The data are presented in tables. A short text contains a brief survey of the measuring methods and discusses the results. The measurements were done in 1965 in the Mineralogical Institute of Basel and were supported by the Schweizerische Geotechnische Kommission.

THE MATERIAL

Specimens were collected (by H.-R. W.) in the whole Lepontine region with some reference specimens from outside the area. The localities for most of them are given in Fig. 1. An attempt was made to get representative samples from all types of rocks. As gneisses and schists are most common and show

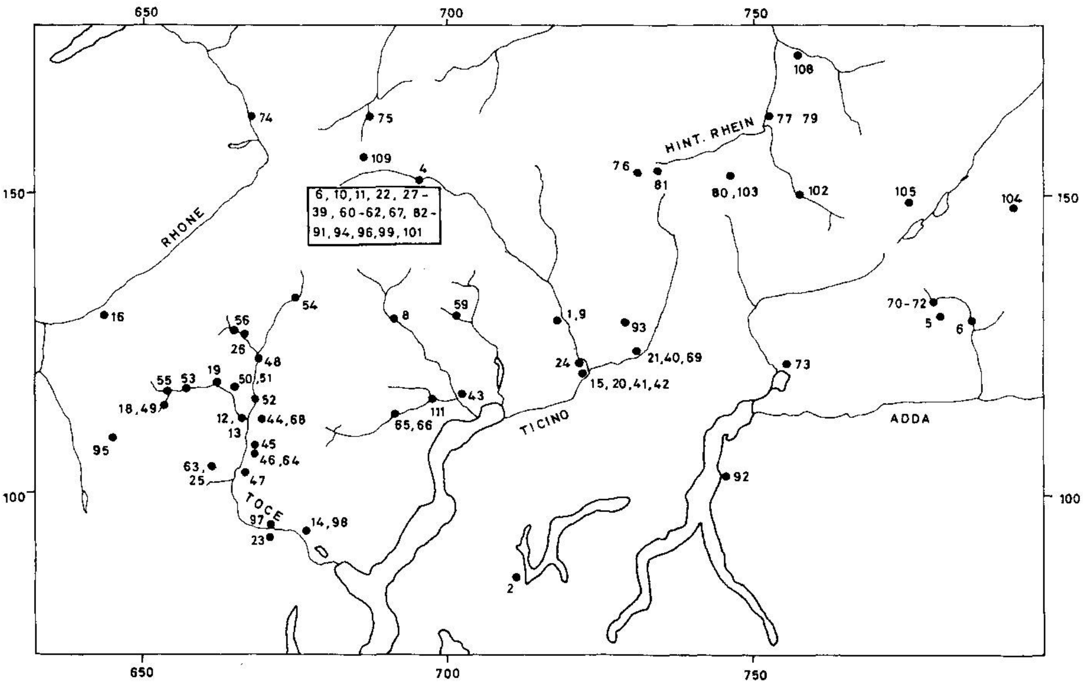

Fig. 1. Map of the Lepontine area with localities of the specimens.

the largest variation in composition and structure, they dominate in number. A detailed survey was made in the upper part of Valle Maggia as heat flow calculations around the Matorello-gneiss appeared to be of great genetic importance. Large pieces (approximately 10×10×20 cm) were collected in order to have sufficient material for all measurements. From these blocks 5×5×5 cm cubes with polished faces and accurate right angles were cut and prepared for heat flow and density (subsequently elastic wave velocity and radiometric data) measurements. Thin sections were analyzed petrographically and descriptions including localities (with coordinates) are given in Table 1 (E. W.). Many feldspar concentrates from specimens described in this paper have been used in other studies (WENK, 1967).

METHODS OF MEASURING

All data are given for room temperature (20° C) and normal pressure (1 bar) and are thus not directly applicable to geological processes. The thermal conductivity decreases generally with increasing temperature (BIRCH and CLARK, 1940). The presently available data for *pT* corrections are compiled in the "Handbook of Physical Constants" (CLARK, 1966). *CGS* (centimeter, gram, second) and caloric units are used. Many measurements were repeated two or more times at different intervals and good reproducibility was found.

Density (g cm^{-3})

The density of dry specimens has been calculated first from volume (cubic samples) and mass, secondly from uplift in water and mass. The two values show small systematic differences due to absorption of water in the uplift experiments and the deviations from ideal cube geometry. An arithmetic mean of the two measurements was used. The error[1]) is ± 0.01 g cm^{-3}.

Porosity (%)

The porosity is measured as a threshold value of water absorption by the unit cube (5×5×5 cm) in water of atmospheric pressure. This state was found to be achieved after about 100 h. The porosity is given as volume percent water-absorption. The error in the data is ± 0.05%.

Specific heat (cal g^{-1} °C^{-1} = $4.184 \cdot 10^7$ erg g^{-1} °C^{-1})

The specific heat was measured in a water-calorimeter at room temperature. The initial temperature difference between sample and water is about 5° C; after heat equalization the water temperature increased 1–2° C. 5 g of crushed

[1]) "Error" is used from here on as variability and reliability of the measurements due to instrumental limits.

rock with a grain size of up to 2 mm served as a specimen. Absolute values corrected for heat losses are obtained by calibration with quartz as external standard. The error is ± 0.005 cal g^{-1} $^\circ C^{-1}$.

Thermal diffusivity (cm^2 sec^{-1})

A detailed description of the experiment is given by Wenk (1964). Cubes of $5 \times 5 \times 5$ cm are used as specimens. They are cut parallel to the main mesoscopic fabric coordinates *a*, *b*, *c*, if visible. On this mesoscopic scale at least the orientation of mica (which is mainly responsible for the anisotropy in heat conduction) shows orthorhombic symmetry in most of the samples, so that the heat conduction properties can be described by an ellipsoid with its main axes parallel to *a*, to *b* (lineation) and to *c* (normal to the foliation). The diffusivities are measured in these three directions. The cubes which are in perfect temperature equilibrium were put on a copper plate about 5° C warmer with constant temperature. The change in temperature on the top side of the rock cube is recorded as a function of time and from these data the thermal diffusivity is calculated using the formula in Carslaw and Jaeger (1959):

$$T_{(t)} = \frac{4\,T_0}{\pi} \sum_{n=0}^{\infty} \frac{(-1)^n}{(2n+1)}\, e^{-\frac{K(2n+1)^2 \pi^2 t}{4 l^2}} .$$

$T_{(t)}$: Temperature difference between top plane of cube and copper-contact at time t.
T_0: Temperature difference between cube and copper plate at the beginning ($\sim$5° C).
l: distance between top plane and copper contact ($\sim$5 cm).
t: time (0–1500 sec).
K: thermal diffusivity.

For heat losses corrections have been made using external standards. The accuracy of the data is $\pm 0.05 \cdot 10^{-2}$ cm^2 sec^{-1}. The relative error is lower. Larger errors in a few cases are possible.

Heat conductivity (erg sec^{-1} cm^{-1} $^\circ C^{-1}$ = $0.2390 \cdot 10^{-7}$ cal sec^{-1} cm^{-1} $^\circ C^{-1}$)

The heat conductivity K is calculated from diffusivity K density ρ and specific heat c, applying the formula

$$K = \rho c K .$$

Discussion

As can be expected from mineralogical composition and structure of the rocks, the measured parameters show a spread over a wide range. The density which reflects mainly the mineralogical composition varies between 2.5 and 3.5 g cm^{-3}. Granites, pegmatites and quartzites give the lower limit. Gneisses,

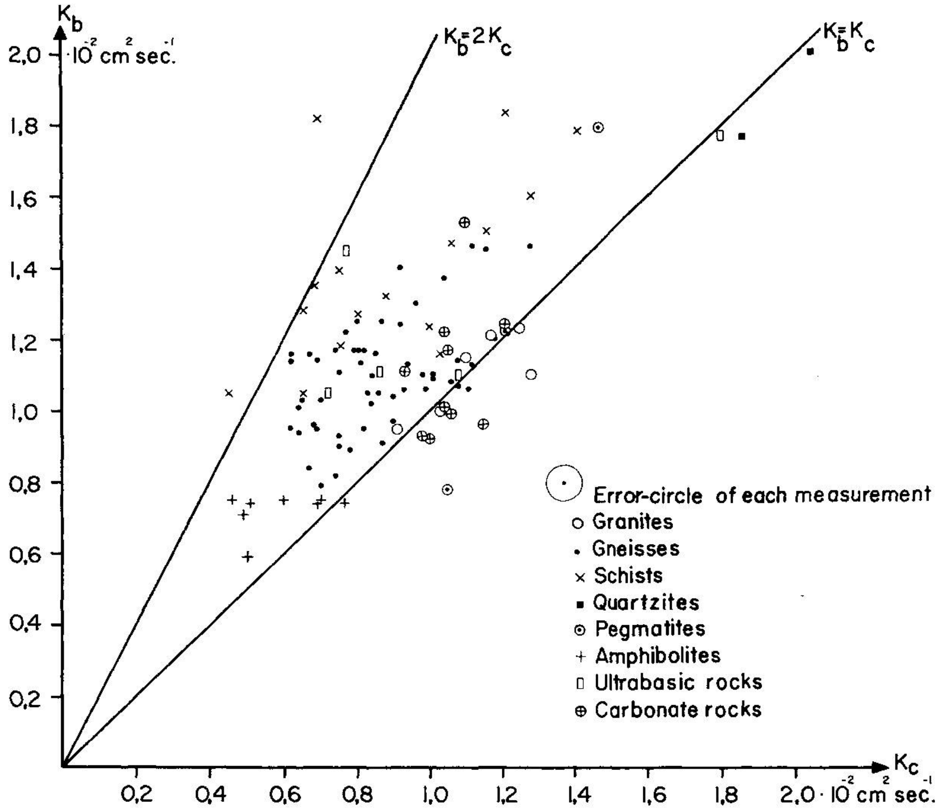

Fig. 2. Anisotropy of heat conduction. K_b (parallel to the lineation) is plotted versus K_c (perpendicular to the foliation).

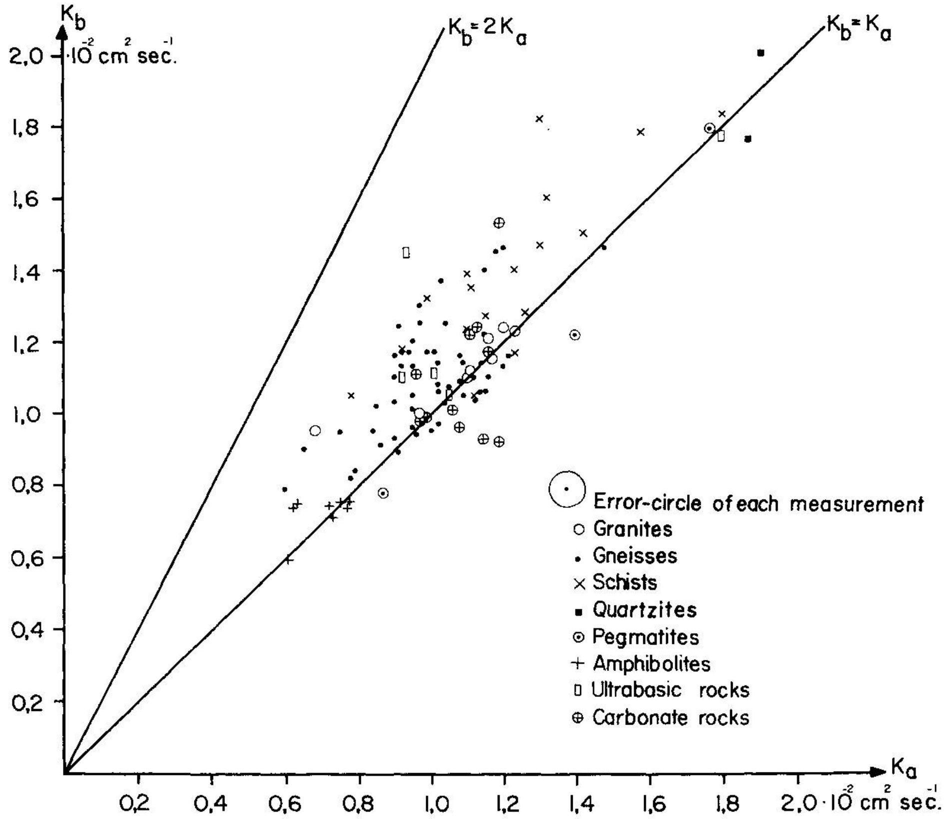

Fig. 3. Anisotropy of heat conduction. K_b is plotted versus K_a.

schists (both depending upon their composition) and carbonate rocks are in the middle class. The highest densities are found in ultrabasic rocks (serpentinites and talc-olivine rocks) and amphibolites. This order follows the densities of the major mineral constituents of the rocks: microcline 2.56 $g\ cm^{-3}$, plagioclase 2.61–2.76, quartz 2.648, calcite 2.712, muscovite 2.83, forsterite 3.21, hornblende 2.9–3.5. Specific heat and porosity don't show any large regular variations and scatter largely in the individual groups. Extremely low porosities are found in marbles, limestones and ultrabasic rocks. A large range of spread almost of an order of magnitude is observed in the thermal diffusivities (0.45–$2.05 \cdot 10^{-2}\ cm^2\ s^{-1}$). Extremely poor heat conductors are schists perpendicular to the foliation and amphibolites. Gneisses, depending upon their mica and hornblende content and their preferred orientation, vary a great deal. Among the best heat conductors are quartzites, talc rocks and granites. Thermal conductivity is a tensor property in the shape of a triaxial ellipsoid. As the studied rocks approximate orthorhombic or higher symmetry at the 5 cm scale, all information is obtained in a first approximation by measuring the conductivity in the three main fabric directions. The best heat flow occurs parallel to the lineation (b) with cases where it is more than twice as large as measured perpendicular to the foliation (c). This large anisotropy is mainly due to preferred orientation of mica which shows a c/b ratio in K of 6.3 (Clark, 1966). The anisotropy of thermal conductivity is illustrated in Figure 2 and Figure 3 where the values parallel to b are plotted versus a and c. A big difference between b and c (well above the 50–50 line) is found in well foliated rocks as in most of the schists. A systematic difference between a and b is less frequent and weaker. It indicates rocks with strong lineation such as pencil-gneisses (Matorello) and some amphibolites. Conductivity could be used as an overall criterion to systematize gneisses according to their preferred orientation. With increasing granitic character they approach the 50–50 line; this is demonstrated in some Rofla-porphyries (No. 77–80) of different metamorphic grade (texture). It is apparent from these data that the anisotropy of heat conduction has to be taken into account in calculations of temperature gradients in orogenic events. Gneisses and schists with strong dips and amphibolites act as good insulators. Such insulators might contribute to the steep metamorphic gradients in all margins of the Lepontine area where subvertical gneiss sequences or abundant amphibolite (Bergell) occur.

Acknowledgments

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Table I. List of Specimens (E. W.)

Specimen number	Petrographic description, Locality, Swiss coordinates
1	Biotite-plagioclase-gneiss (Leventina-gneiss), schistosity poor, quarry S of Lodrino, Riviera (TI) 718.7/128.2
2	Limestone, fine-grained, massive, concretion in Oxfordian marls, quarry near Liesberg, Jura mountains (BE)
3	Granophyre, Permian, quarry near Cuasso al Monte above Lago di Lugano (Italy) 711.5/85.3
4	Clinozoisite-plagioclase-calcite-mica schist, Bündnerschiefer, road in Riale Secco above Ambri, Leventina (TI) 695.25/151.75
5	Chlorite-olivine-pyroxene-talc-serpentinite, clinohumite-bearing, eastern moraine of Vedretta della Ventina, Disgrazia, Val Malenco (Italy) 780.20/129.50
6	Antigorite-schist, olivine-bearing, with excellent lineation, cave di ardesia, near Chiesa, Val Malenco (Italy) 785.5/128.6
7	Biotite-granite (Blasien-granite), Wehra Valley below Todtmoos, Black Forest (Germany) 642.0/286.0
8	Biotite-plagioclase-gneiss, fine- to medium-grained, with good lineation, quarry near Riveo, Valle Maggia (TI) 691.3/128.2
9	Muscovite-biotite-gneiss, medium-grained, leucocratic (Leventina-gneiss), quarry S of Lodrino, Riviera (TI) 718.7/128.2
10	Calcite-marble, quarry Gheiba in Val Peccia (TI) 688.9/142.8
11	Calcite-marble, white, quarry Gheiba in Val Peccia (TI) 688.9/142.8
12	Phlogopite-calcite-marble, banded, quarry Enso near Crevola (Italy) 665.85/112.1
13	Dolomite-marble, muscovite-bearing, fine-grained, gray, quarry Enso near Crevola (Italy) 665.85/112.1
14	Calcite-marble, yellow, quarry Candoglia (Italy) 676.8/93.1
15	Calcsilicate-marble, road Gorduno–ai Sirt, Riviera (TI) 772.6/120.2
16	Slate, quarry Brigerberg (VS) 643.7/129.5
17	Limestone, gray, quarry above Saillon (VS) 580.0/114.0
18	Calcite-marble, muscovite-bearing, Bellegg, Zwischbergental (VS) 653.15/114.1
19	Calcite-plagioclase-mica-schist, Bündnerschiefer, Val Cairasca, Bertonio near Varzo (Italy) 661.3/118.1
20	Scapolite-andesine-diopside-amphibolite, calcite-bearing, Sassa above Gorduno (TI) 722/120.3
21	Plagioclase-amphibolite, banded, lineated, Val Calanca, north of second gallery (GR) 730.5/123.7
22	Epidote-amphibolite, lineated, Lago di Sambuco, road near Riale Sassello (TI) 692.15/147.7
23	Plagioclase-pyroxene-amphibolite, Ivrea zone, quarry near Anzola (Italy) 670.8/093.1
24	Garnet-olivine-fels, talc-bearing, Val Gnosca (TI) 721.9/121.4
25	Soapstone, rich in talc and tremolite, with relics of olivine, old quarry near Cava di Mica, Montescheno (Italy) 660.0/103.7

26 Garnet-mica schist, quartz-rich, Baceno-schist, Val Devero, road-bridge below Croveo (Italy)
666.1/125.9
27 Epidote-biotite-gneiss, coarse-grained, with good lineation and poor schistosity, Matorello-gneiss, road-cut below Laghetto, Val Sambuco (TI)
688.7/148.0
28 Garnet-biotite-muscovite-schist, sheared, Lago Sambuco (TI)
691.6/148.0
29 Garnet-biotite-muscovite-schist, quartz-rich, with good lineation, road near A. Bolla, Sambuco (TI)
691.12/148.45
30 Muscovite-biotite-plagioclase-gneiss, microcline perthite-bearing lineated, SE of Laghetto 2128, Val Sambuco (TI)
688.4/147.2
31 Plagioclase-muscovite-biotite-schist, folded with good lineation, Lago Sambuco (TI)
688.2/147.78
32 Biotite-muscovite-plagioclase-gneiss, leucocratic, with good lineation, Lago Sambuco, N R. Valgello (TI)
692.94/147.18
33 Muscovite-plagioclase-gneiss, leucocratic (cube cut obliquely to the s-plane), Lago Sambuco NE R. Scheggia (TI)
692.97/146.94
34 Mica-plagioclase-gneiss, folded with good lineation, Lago Sambuco, 70 m N R. Scheggia (TI)
693.04/146.88
35 Biotite-plagioclase-gneiss, folded with good lineation, Lago Sambuco, 7 m N R. Scheggia (TI)
693.04/146.88
36 Muscovite-biotite-plagioclase-gneiss, Lago Sambuco, 20 m N R. Massari (TI)
693.9/146.08
37 Garnet-cyanite-staurolite-mica-schist, road near A. Bolla, Sambuco (TI)
691.12/148.45
38 Biotite-plagioclase-gneiss, mesocratic, fine-grained, lineated, road Sambuco, SE A. Campo di Sotto (TI)
690.95/148.6
39 Potash feldspar-muscovite-biotite-plagioclase-gneiss, with good lineation (Matorello-gneiss), A. Lait near 2171, Sambuco (TI)
688.2/147.78
40 Veined mica-perthite-plagioclase-gneiss, new road Val Calanca below 1st gallery
730/123.7
41 Hornblende-biotite-plagioclase-gneiss, veined, with good lineation, road Gorduno ai Sirt, above Gorduno (TI)
722.6/119.6
42 Biotite-plagioclase-gneiss, microcline-bearing, banded, with good lineation, road Gorduno–ai Sirt, above Gorduno (TI)
722.6/119.6
43 Muscovite-biotite-plagioclase-microcline-gneiss, fine-grained, quarry near Ponte Brolla, Valle Maggia (TI)
701.7/116.3
44 Epidote-biotite-potash-feldspar-plagioclase-gneiss, fine-grained (Monte-Leone-gneiss), Val Isorno, S of Naviledo near Domodossola (Italy)
669.5/112.0
45 Muscovite-biotite-plagioclase-microcline-gneiss, quarry N of Croppo near Domodossola (Italy)
667.8/107.2
46 Biotite-plagioclase-microcline-gneiss, with good lineation, quarry S of Croppo near Domodossola (Italy)
667.8/106.65
47 Muscovite-biotite-plagioclase-microcline-augengneiss, with excellent lineation (zone of Monte Rosa-Locarno), quarry near Beura (Italy)
666.2/102.7
48 Biotite-plagioclase-microcline-gneiss (Verampio-gneiss), quarry Verampio near Crodo, Val Antigorio (Italy)
668.85/121.7

49 Biotite-microcline-plagioclase-gneiss (Antigorio-gneiss), sheared with good lineation, road near Bellegg, Zwischbergental (VS)
653.15/114.1
50 Epidote-muscovite-biotite-plagioclase-microcline perthite-augengneiss, lineated (Antigorio-gneiss), quarry near Campaglia below Varzo (Italy)
664.55/116.4
51 Muscovite-plagioclase-microcline-gneiss, biotite and garnet-bearing, leucocratic, fine-grained, equigranular, aplitic vein in Antigorio-gneiss, quarry near Campaglia below Varzo (Italy)
664.55/116.4
52 Biotite-plagioclase-microcline perthite-augengneiss, epidote-orthite-bearing, mesocratic (Antigorio-gneiss), quarry near Rencio, Val Antigorio (Italy)
667.7/116.3
53 Epidote-muscovite-biotite-plagioclase-microcline-gneiss, lineated (Antigorio-gneiss), between Iselle and Confine, Balmoreglio (Italy)
657.0/117.0
54 Biotite-microcline perthite-plagioclase-augengneiss, sphene- and epidote-bearing (Antigorio-gneiss), quarry at bridge SW Antillone, Foppiano, Val Formazza (Italy)
674.7/131.8
55 Muscovite-biotite-plagioclase-microcline perthite-augengneiss, sphene- and epidote-bearing, lineated (Antigorio-gneiss), quarry near Gondo (VS)
654.0/116.2
56 Biotite-hornblende-plagioclase-gneiss, calcite-, sphene- and chlorite-bearing, outcrops below road-bridge E of Goglio, Val Devero (Italy)
664.6/126.6
57 Biotite-plagioclase-gneiss, muscovite-, calcite- and sphene-bearing, mesocratic, with good lineation (Verzasca-gneiss, dark variety), quarry Soriolo, Valle d'Osola (TI)
702.9/128.5
58 Biotite-muscovite-perthite-oligoclase-gneiss, leucocratic, lineated (Verzasca-gneiss), quarry Togni, Brione-Verzasca, Valle d'Osola (TI)
703.3/128.5
59 Muscovite-biotite-plagioclase-potash feldspar-augengneiss, with good lineation, boulder in Valle d'Osola (TI)
701.2/129.4
60 Muscovite-oligoclase-gneiss, garnet- and potash feldspar-bearing, leucocratic, lineated, Lago Sambuco (TI)
692.3/147.53
61 Muscovite-albite-potash feldspar-gneiss, garnet- and biotite-bearing, quartz-rich, leucocratic, lineated, trail above Erta, Val Peccia (TI)
689/143.4
62 Muscovite-biotite-albite-potash feldspar-gneiss, garnet-bearing, folded, with good lineation, river-gorge NNE A. Froda, Val Peccia (TI)
688.6/145.8
63 Pegmatite, muscovite-bearing, cataclastic, Cava di Mica, Montescheno (Italy)
660.9/103.7
64 Muscovite-pegmatite, garnet-bearing, quarry S of Croppo near Domodossola (Italy)
667.8/106.65
65 Sericite-pegmatite, prehnite-bearing, kakiritic, Centovalli-road between Verdasio and Camedo (TI)
691.5/112.6
66 Plagioclase-amphibolite, prehnite-bearing, folded and sheared, Centovalli-road between Verdasio and Camedo (TI)
691.5/112.6
67 Clinozoisite-biotite-plagioclase-amphibolite, "lamprophyre" with good lineation, in valley SE Laghetto 2128, Val Sambuco (TI)
688.4/147.2
68 Plagioclase-muscovite-biotite-schist, garnet-bearing, quartz-rich (Baceno-schist), Verampio near Crodo, Val Antigorio (Italy)
668.9/112.1
69 Garnet-cyanite-biotite-plagioclase-gneiss, mesocratic, with good lineation, new road-cuts in Val Calanca (GR)
731.1/123.2

70 Epidote-biotite-hornblende-quartzdiorite, tonalite, gneissose, lineated, boulder in Val Sissone, Val Malenco (Italy)
779.5/131.5
71 Epidote-biotite-hornblende-quartzdiorite = tonalite, gneissose, lineated, boulder in Val Sissone, Val Malenco (Italy)
779.5/131.5
72 Hornblende-biotite-granite, sphene-bearing (Bergeller-granite), boulder in Val Sissone, Val Malenco, from Muretto (Italy)
131.5/779.5
73 Muscovite-granite, biotite- and garnet-bearing, gneissose (Novate-granite), quarry near Novate (Italy)
755.2/121.3
74 Meta-granite, stilpnomelane-, epidote- and chlorite-bearing, lineated (Aar-granite), quarry above Handegg, Grimsel (BE)
667.3/162
75 Biotite-plagioclase-microcline perthite-gneiss, epidote-bearing, Mesocratic (Gamsboden-gneiss), Gamsboden, Gotthard (UR)
686.5/162.3
76 Epidote-phengite-plagioclase-microcline-gneiss, leucocratic, with good lineation (Adula-gneiss), quarry above Hinterrhein (GR)
731.0/153.3
77 Meta-quartzporphyry, rich in sericite, carbonate-bearing, with relictic phenocrysts of quartz and perthitic potash feldspar, with good lineation (Rofla-porphyry), quarry Bärenburg near Andeer (GR)
752.0/162.3
78 Idem, but inhomogeneous, with augen-structure, lineated (Rofla-porphyry), quarry Bärenburg near Andeer (GR)
752.0/162.3
79 Idem, schistose, lineated (Rofla-porphyry), quarry Bärenburg near Andeer (GR)
752.0/162.3
80 Idem, cataclastic and rather massive variety of Rofla-porphyry, pipeline-tunnel of Splügen-Pass (GR)
745.6/152.7
81 Epidote-phengite-microcline-albite-gneiss, chlorite- and biotite-bearing, mesocratic, lineated, with fine-medium augen-structure (Adula gneiss), quarry Tälli, Bernardin pass (GR)
734.2/153.5
82 Carbonate-biotite-microcline-gneiss, plagioclase- and muscovite-bearing, lineated (Lebendun gneiss), summit of Pizzo Basodino (TI)
679.2/140.6
83 Muscovite-biotite-plagioclase-microcline-gneiss (Lebendun-gneiss), lower end of Basodino Glacier, E of Pt. 2658.6 (TI)
142.1/680.2
84 Idem (Lebendun-gneiss), lower end of Basodino Glacier, E. of Pt. 2658.6 (TI)
680.2/142.1
85 Muscovite-biotite-plagioclase-microcline-gneiss, diaphthoritic, lineated (Lebendun-gneiss), Caralina, WSW of Robiei (TI)
680.55/142.65
86 Muscovite-biotite-plagioclase-microcline-augengneiss, lineated (Lebendun-gneiss), lower part of Basodino Glacier, NE of Pt. 2463 (TI)
141.3/681.61
87 Garnet-biotite-muscovite-plagioclase-calcite-schist, lineated (Bündnerschiefer), W of dam Robiei (TI)
682.7/144.2
88 Plagioclase-muscovite-biotite-carbonate-microcline perthite-schist, mesocratic, diaphthoritic, with excellent lineation, Val Cavagnoli below Pt. 2322.6 (TI)
682.3/145.4
89 Chlorite-garnet-muscovite-biotite-calcite-plagioclase-schist (Bündnerschiefer), Val Bavona (TI)
683.3/142.2
90 Calcite-clinozoisite-plagioclase-garnet-phyllite, lineated, Val Cavagnoli (TI)
681.1/146.1
91 Garnet-muscovite-biotite-schist (Bündnerschiefer), A. Robiei (TI)
682.55/143.8

92 Plagioclase-staurolite-garnet-muscovite-biotite-schist, lineated (Insubric zone), Lago di Como near Dervio (Italy)
744.85/103.3

93 Microcline-biotite-plagioclase-gneiss, orthite-bearing, mesocratic, lineated, quarry Arvigo, Val Calanca (GR)
729.2/128.5

94 Potash feldspar-muscovite-biotite-plagioclase-gneiss, leucocratic, fine-grained, with good lineation, diaphthoritic, Lago Sambuco (TI)
688.2/147.78

95 Chlorite-garnet-muscovite-albite-gneiss, tourmaline-bearing, with good lineation, eastern summit of Weissmies (VS)
644.55/108.5

96 Plagioclase-muscovite-carbonate-quartz-schist, biotite-bearing, lineated, Val Cavagnoli (TI)
681.1/146.1

97 Microcline perthite-garnet-sillimanite-granofels, mylonitic ("stronalite" of Ivrea zone), Torrente Crotto near Cuzzago, Valle d'Ossola (Italy)
670.7/94.7

98 Calcite-marble, quartz-bearing, quarry Candoglia (Italy)
676.8/93.1

99 Calcite-dolomite-marble, quartz-bearing, inhomogeneous, lineated (Trias), A. Robiei (V. Bavona, TI)
683.15/144.3

100 Muscovite-quartzite, albite-bearing, lineated, Zwischbergenpass (VS)
645/107.3

101 Muscovite-carbonate-microcline-quartz-schist, lineated, A. Lago Bianco, Val Bavona (TI)
682.75/145.55

102 Sericite-quartzite, microcline-bearing, lineated, quarry N of Croet, Avers (GR)
757.4/149.2

103 Meta-quartzporphyry, with relictic phenocrysts of quartz and albite, mylonitic, with good lineation, cube cut obliquely to S, Splügenpass (GR)
745.6/152.7

104 Meta-alkaligranite, mesocratic, orthite- and stilpnomelane-bearing, rich in perthite (Bernina-granite), Bernina-passroad, 1 km N of station Morteratsch (GR)
792.35/148.2

105 Perthite-saussurite-meta-biotite-granite, orthite-, stilpnomelane- and chlorite-bearing (Julier-granite), Julier-pass, La Veduta (GR)
775.0/149.0

106 Pyroxene-forsterite-antigorite-schist, lineated, quarry near Selva, Poschiavo (GR)
800.0/131.2

107 Marble, fine-grained, lineated, quarry near Selva, Poschiavo (GR)
800.0/131.2

108 Chlorite-quartz-calcite-schist (Bündnerschiefer), Schinschlucht, road-tunnel (GR)
757/173.3

109 Perthite-muscovite-biotite-plagioclase-augengneiss, lineated (Fibbiagneiss), new road-cut SW of Gotthard-Hospiz (TI)
686.1/156.

110 Meta-biotite-granite, gneissose, medium-grained, homogeneous, rich in microcline perthite and saussurite (Aar-granite), Baltschiedertal below Martischüpfe (VS)
633.8/134.8

111 Plagioclase-biotite-microcline-gneiss, rich in myrmekite, banded and lineated, quarry Isorno-bridge, near Intragna (TI)
697.2/115.2

Table II. Physical Constants (H.-R. W.)

Specimen number	Area Code	Density	Porosity	Heat Capacity		Diffusivity			Thermal Conductivity		
	Unit:	g cm^{-3}	Vol.-%	cal g^{-1} °C^{-1}	erg g^{-1} °C^{-1} 10^5	a cm^2	b s^{-1}	c 10^{-2}	a erg s^{-1}	b cm^{-1} °C^{-1}	c 10^3
	Error:	±0.01	±0.05	±0.005		±0.05					
Granites											
3	Malcantone	2.60	2.3	0.19	4.5	1.20	1.24		14.8	14.8	
7	Schwarzwald	2.64	0.2	0.17	4.1	1.11	1.12		12.1	12.2	
72	Bergell	2.65	1.0	0.19	4.5	0.68	0.95	0.91	8.3	11.6	11.1
73	Novate	2.62	0.8	0.19	4.5	0.97	1.00	1.03	11.7	12.0	12.4
74	Grimsel	2.60	0.8	0.18	4.3	1.23	1.23	1.25	13.9	13.9	14.1
104	Bernina	2.62	0.6	0.16	3.8	1.10	1.10	1.28	11.2	11.2	13.0
105	Julier	2.70	0.8	0.18	4.3	1.17	1.15	1.10	13.7	13.5	12.9
110	Baltschiedertal	2.63	2.0	0.18	4.3	1.16	1.21	1.17	13.3	13.8	13.4
Gneisses											
1	Leventina	2.75	0.9	0.18	4.3	0.75	0.95	0.62	9.0	11.4	7.4
8	Maggia	2.70	0.8	0.18	4.3	0.96	0.94	0.64	11.3	11.0	7.5
9	Leventina	2.67	0.3	0.16	3.8	1.09	1.14	0.74	11.3	11.8	7.7
27	Matorello	2.64	2.4	0.18	4.3	1.15	1.06	0.93	13.2	12.2	10.7
30	Sambuco	2.69	0.9	0.20	4.8	0.95	1.01	0.64	12.3	13.1	8.3
32	Sambuco	2.66	0.7	0.19	4.5	0.95	1.13	0.81	11.6	13.8	9.9
33	Sambuco	2.67	0.7	0.18	4.3	1.12	1.04	0.90	13.0	12.1	10.5
34	Sambuco	2.68	0.8	0.19	4.5	0.84	0.95	0.69	10.3	11.7	8.5
35	Sambuco	2.68	1.0	0.19	4.5	0.90	1.03	0.70	11.1	12.7	8.6
36	Sambuco	2.69	0.9	0.18	4.3	0.85	1.02	0.84	9.9	11.9	9.8
38	Sambuco	2.71	0.9	0.18	4.3	1.04	1.03	0.65	12.3	12.1	7.7
39	Matorello	2.67	1.5	0.18	4.3	0.95	0.96	0.68	11.0	11.2	7.9
40	Calanca	2.64	1.1	0.19	4.5	1.10	1.16	0.84	13.3	14.1	10.2
41	Riviera	2.71	1.0	0.19	4.5	0.86	0.91	0.87	10.7	11.3	10.8
42	Riviera	2.71	1.0	0.18	4.3	0.79	0.84	0.67	9.3	9.9	7.9
43	Maggia	2.67	1.0	0.19	4.5	0.92	1.17	0.82	11.3	14.3	10.0
44	Mte. Leone	2.64	1.0	0.18	4.3	0.78	0.82	0.74	9.0	9.4	8.5
45	Domodossola	2.65	1.0	0.18	4.3	0.65	0.90	0.75	7.5	10.4	8.6
46	Domodossola	2.65	0.8	0.20	4.8	0.99	1.17	0.74	12.7	15.0	9.5
47	Beura	2.64	0.8	0.17	4.1	0.94	1.17	0.80	10.2	12.7	8.7
48	Antigorio	2.64	0.8	0.17	4.1	1.08	1.16	0.67	11.7	12.6	7.3
49	Antigorio	2.61	1.2	0.17	4.1	0.97	1.25	0.80	10.4	13.4	8.6
50	Antigorio	2.64	1.0	0.16	3.8	0.90	1.16	0.85	9.2	11.9	8.7
51	Antigorio	2.60	1.1	0.17	4.1	1.08	1.09	1.01	11.5	11.7	10.8
52	Antigorio	2.69	1.1	0.19	4.5	0.90	0.93	0.75	11.1	11.5	9.3
53	Antigorio	2.64	1.1	0.19	4.5	0.91	0.89	0.78	11.0	10.8	9.5
54	Antigorio	2.67	0.9	0.18	4.3	1.02	0.97	0.90	11.8	11.3	10.5
55	Antigorio	2.63	1.0	0.18	4.3	0.95	1.05	0.83	10.9	12.0	9.5

Specimen number	Area Code	Density	Porosity	Heat Capacity		Diffusivity			Thermal Conductivity		
	Unit:	g cm^{-3}	Vol.-%	cal g^{-1} °C^{-1}	erg g^{-1} °C^{-1} 10^5	a cm^2	b s^{-1}	c 10^{-2}	a erg s^{-1}	b cm^{-1} °C^{-1}	c 10^3
	Error:	±0.01	±0.05	±0.005		±0.05					
56	Devero	2.68	1.1	0.17	4.1	0.60	0.79	0.70	6.6	8.7	7.7
57	Verzasca	2.72	0.7	0.20	4.8	0.95	1.11	0.75	12.5	14.6	9.9
58	Verzasca	2.65	0.9	0.17	4.1	1.12	1.10	1.01	12.2	12.0	11.0
59	Verzasca	2.64	1.2	0.22	5.3	1.00	0.95	0.82	14.0	13.3	11.5
60	Sambuco	2.60	1.3	0.17	4.1	1.14	1.14	1.08	12.2	12.2	11.5
61	Peccia	2.61	0.9	0.18	4.3	1.01	1.17	0.80	11.5	13.3	9.1
62	Peccia	2.61	0.8	0.19	4.5	1.05	1.07	1.08	12.6	12.8	12.9
69	Calanca	2.73	0.7	0.17	4.1	1.02	1.14	0.62	11.5	12.8	7.0
75	Gotthard	2.66	0.8	0.19	4.5	1.14	1.06	1.11	13.9	12.9	13.6
76	Adula	2.62	0.8	0.19	4.5	1.22	1.16	0.62	14.7	14.0	7.5
77	Rofla	2.71	0.7	0.18	4.3	1.04	1.25	0.87	12.3	14.7	10.3
78	Rofla	2.71	0.7	0.17	4.1	0.97	1.30	0.97	10.8	14.5	10.8
79	Rofla	2.70	0.7	0.16	3.8	0.91	1.24	0.92	9.5	13.0	9.6
80	Splügen	2.68	0.9	0.17	4.1	1.03	1.37	1.04	11.4	15.1	11.5
81	Adula	2.65	1.0	0.19	4.5	1.02	1.06	0.99	12.4	12.9	12.0
82	Basodino	2.62	1.4	0.18	4.3	0.90	1.10	0.98	10.3	12.5	11.2
83	Basodino	2.67	1.1	0.18	4.3	1.15	1.22	0.77	13.4	14.2	8.9
84	Basodino	2.65	1.0	0.20	4.8	1.18	1.45	1.16	15.1	18.6	14.8
85	Robiei	2.65	1.0	0.18	4.3	1.20	1.46	1.12	13.8	16.8	12.9
86	Basodino	2.63	1.1	0.19	4.5	1.02	1.08	1.06	12.3	13.0	12.8
93	Calanca	2.67	1.0	0.19	4.5	1.09	1.05	0.86	13.4	12.9	10.5
94	Sambuco	2.66	1.1	0.17	4.1	0.92	1.13	0.98	10.1	12.4	10.7
95	Weissmies	2.73	1.2	0.19	4.5	1.15	1.40	0.92	14.4	17.5	11.5
97	Ivrea	2.95	0.5	0.17	4.1	1.48	1.46	1.28	18.0	17.7	15.5
103	Splügen	2.67	0.3	0.11	2.6	1.57	1.57	1.27	11.2	11.2	9.1
109	Gotthard	2.63	0.9	0.19	4.5	1.20	1.13	1.12	14.5	13.6	13.5
111	Centovalli	2.63	2.0	0.18	4.3	0.95	1.20	1.18	10.9	13.7	13.5
Schists											
4	Leventina	2.73	0.2	0.18	4.3	1.30	1.47	1.06	15.4	17.5	12.6
16	Brig	2.86	0.6	0.19	4.5	1.80	1.83	1.21	23.6	24.0	15.9
19	Varzo	2.71	0.5	0.19	4.5	1.22	1.16	1.03	15.2	14.4	12.8
26	Baceno	2.74	1.7	0.25	6.0	1.26	1.28	0.65	20.8	21.1	10.7
28	Sambuco	2.79	1.1	0.19	4.5	1.10	1.39	0.75	14.1	17.8	9.6
29	Sambuco	2.77	0.7	0.18	4.3	1.12	1.45	0.83	13.5	17.5	10.0
31	Sambuco	2.73	0.7	0.20	4.8	0.78	1.05	0.65	10.3	13.8	8.6
37	Sambuco	2.86	0.7	0.19	4.5	1.30	1.82	0.69	17.1	23.9	9.1
68	Baceno	2.74	1.2	0.17	4.1	1.12	1.05	0.45	12.6	11.8	5.1
87	Robiei	2.76	0.3	0.19	4.5	1.42	1.50	1.16	18.0	19.0	14.7
88	Cavagnoli	2.72	0.5	0.18	4.3	0.99	1.32	0.88	11.7	15.6	10.4
89	Bavona	2.77	0.5	0.19	4.5	1.10	1.23	1.00	14.0	15.6	12.7

90	Cavagnoli	2.73	0.4	0.19	4.5	1.32	1.60	1.28	16.5	20.0	16.0
91	Robiei	2.84	1.2	0.20	4.8	1.11	1.35	0.68	15.2	18.5	9.3
92	Dervio	2.93	0.9	0.18	4.3	0.92	1.18	0.75	11.7	15.0	9.6
96	Cavagnoli	2.66	0.7	0.18	4.3	1.58	1.78	1.41	18.3	20.6	16.3
101	Cavagnoli	2.60	1.1	0.16	3.8	1.23	1.40	1.40	12.4	14.1	14.1
108	Schin	2.69	0.7	0.18	4.3	1.15	1.27	0.80	13.5	14.9	9.4
Quartzites											
100	Weissmies	2.64	0.7	0.17	4.1	1.87	1.76	1.86	20.3	19.1	20.2
102	Avers	2.64	0.7	0.22	5.3	1.92	2.05	2.08	26.9	28.7	29.1
Pegmatites											
63	Montescheno	2.62	0.7	0.17	4.1	1.77	1.78	1.47	19.1	19.2	15.8
64	Domodossola	2.63	0.7	0.20	4.8	1.40	1.22	1.21	17.8	15.5	15.4
65	Centovalli	2.57	2.1	0.16	3.8	0.87	0.78	1.05	8.7	7.8	10.5
Amphibolites											
20	Riviera	3.06	0.6	0.16	3.8	0.77	0.74	0.68	9.1	8.8	8.1
21	Calanca	2.87	1.7	0.18	4.3	0.77	0.75	0.60	9.6	9.4	7.5
22	Sambuco	2.97	2.2	0.17	4.1	0.61	0.59	0.50	7.4	7.2	6.1
23	Anzola	3.10	0.3	0.17	4.1	0.75	0.75	0.70	9.6	9.6	8.9
66	Centovalli	2.69	2.3	0.21	5.0	0.62	0.74	0.77	8.5	10.1	10.5
67	Sambuco	2.84	1.6	0.17	4.1	0.63	0.75	0.46	7.4	8.8	5.4
70	Sissone	2.80	0.7	0.17	4.1	0.72	0.74	0.51	8.3	8.5	5.9
71	Sissone	2.79	0.8	0.17	4.1	0.73	0.71	0.49	8.4	8.1	5.6
Ultrabasic rocks											
5	Disgrazia	2.72	0.6	0.21	5.0	1.05	1.05	0.72	14.5	14.5	9.9
6	Malenco	2.79	0.0	0.21	5.0	0.93	1.45	0.77	13.1	20.5	10.9
24	Riviera	3.16	0.1	0.20	4.8	0.92	1.10	1.08	14.0	16.8	16.5
25	Montescheno	2.95	0.1	0.24	5.7	1.80	1.77	1.80	30.7	30.2	30.7
106	Poschiavo	2.77	0.2	0.23	5.5	1.01	1.11	0.86	15.5	17.1	13.2
Carbonate rocks											
2	Jura	2.51	1.0	0.20	4.8	0.97	0.98		11.8	11.9	
10	Peccia	2.69	0.1	0.16	3.8	1.15	0.93	0.98	12.0	9.7	10.2
11	Peccia	2.70	0.1	0.17	4.1	1.19	0.92	1.00	13.2	10.2	11.1
12	Crevola	2.84	0.4	0.18	4.3						
13	Crevola	2.84	0.5	0.22	5.3	1.11	1.22	1.04	16.7	18.4	15.7
14	Candoglia	2.71	0.2	0.20	4.8	1.06	1.01	1.04	13.9	13.2	13.6
15	Riviera	2.75	0.1	0.18	4.3	1.08	0.96	1.15	12.9	11.5	13.8
17	Valais	2.69	1.1	0.19	4.5	0.99	0.99	1.06	12.2	12.2	13.1
18	Simplon	2.71	0.3	0.18	4.3	0.95	1.11	0.93	11.2	13.1	11.0
98	Candoglia	2.71	0.1	0.20	4.8	1.16	1.17	1.05	15.2	15.3	13.7
99	Robiei	2.77	0.2	0.18	4.3	1.13	1.24	1.20	13.6	14.9	14.5
107	Poschiavo	2.83	1.2	0.19	4.5	1.19	1.53	1.10	15.5	19.9	14.3