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Rb-Sr Systems in Different Degrees of Metamorphism

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ABSTRACT

Rb-Sr systems in different minerals and total rocks were studied in areas of different degrees of Alpine metamorphism. Three mechanisms are described which influence the Rb-Sr systems of total rock samples:

(1) Chemical inhomogenity between aplite dyke and the country rock favours an exchange process at elevated temperatures.
(2) In the gneisses of the front part of Pennine nappes Sr-redistribution was found. The special conditions of these rocks are the close proximity to sediments and intensive deformation and fracturing.
(3) Anatectic conditions cause at least partial redistribution of the Rb-Sr total rock systems.

Introduction

For three reasons the Alps are a favourable region in which to study the relation between the grade of metamorphism and the behavior of Rb-Sr systems:

a) The low age values give small absolute errors in the range of m.y. The high resolution permits the detection of several phases of Alpine metamorphism. The latest phase (boundary Eocene-Oligocene) can be dated in different stages: the climax with formation of new minerals and the different stages of the cooling following the climax.
b) After the last phase of Alpine metamorphism nothing happened to the rocks.
c) The Alps are well studied, the zones of minerals formed by the Alpine metamorphism are well described. For several mineral-transitions the conditions of their formation are quite well established, as the transition chloritoid-staurolite. If then the regional distribution of Rb-Sr age data is compared with the metamorphic zones, conclusions can be reached under which conditions the Rb-Sr systems acted as open or closed systems.

Rb-Sr Studies on Different Minerals

Total rock samples, major rock forming minerals (micas and feldspars) as well as the accessory minerals, garnets, apatite, epidote and fluorite, were analyzed. The rocks were sampled along a N-S profile through the Central Alps, from the Aar massif in the north to the Gotthard massif, the Pennine nappes and their roots in the south. A tectonic map together with Rb-Sr ages on biotites of this area is given by J.C. HUNZIKER, this volume. Our profile starts in the center of the Aar massif, in the zone of Alpine stilpnomelane. To the south the degree of Alpine metamorphism increases to the formation of chloritoid and further to the south to the zones of Alpine kyanite and staurolite, see E. NIGGLI and C. R. NIGGLI, 1965. In pairs of coexisting plagioclase and calcite, the anorthite content in plagioclase increases from pure albite in the north to plagioclase with an anorthite content of more than 70% in the south, see E. WENK, 1962.

In the outer part of the Aar massif, in the north-western zone, even the most sensitive mineral, biotite, preserved its pre-Alpine age (Gastern-granite 275 m.y. and Erstfelder gneiss 298 m.y.), see H. WÜTHRICH, 1965. In the central part of the Aar massif, in the zone of stilpnomelane, we find the transition zone from pre-Alpine to young Alpine biotite ages in the range of 10 to 30 m.y., see E. JÄGER, E. NIGGLI and E. WENK, 1967, and J. C. HUNZIKER, this volume. In the transition zone the intermediate age results depend on the resistance of the rock to metamorphism. A. ARNOLD and E. JÄGER, 1965, found within a distance of only 8 m quite different Rb-Sr ages on biotite, depending on the degree of Alpine recrystallization of the rock. The rock with the most intensive recrystallization gave the youngest Rb-Sr biotite age.

In the inner part of the stilpnomelane zone biotites may be completely rejuvenated by the Alpine metamorphism while muscovites from this zone always give pre-Alpine ages. No Alpine Sr-homogenisation was reached among the different minerals.

H. WÜTHRICH, 1965, analyzed different minerals and the total rock sample from the aplite Kessiturm, Aar massif. This rock is situated in the transition zone between Alpine stilpnomelane and chloritoid. The Sr-evolution diagram of these analyses is presented in Figure 1. The biotite-total rock isochron corresponds to an age of

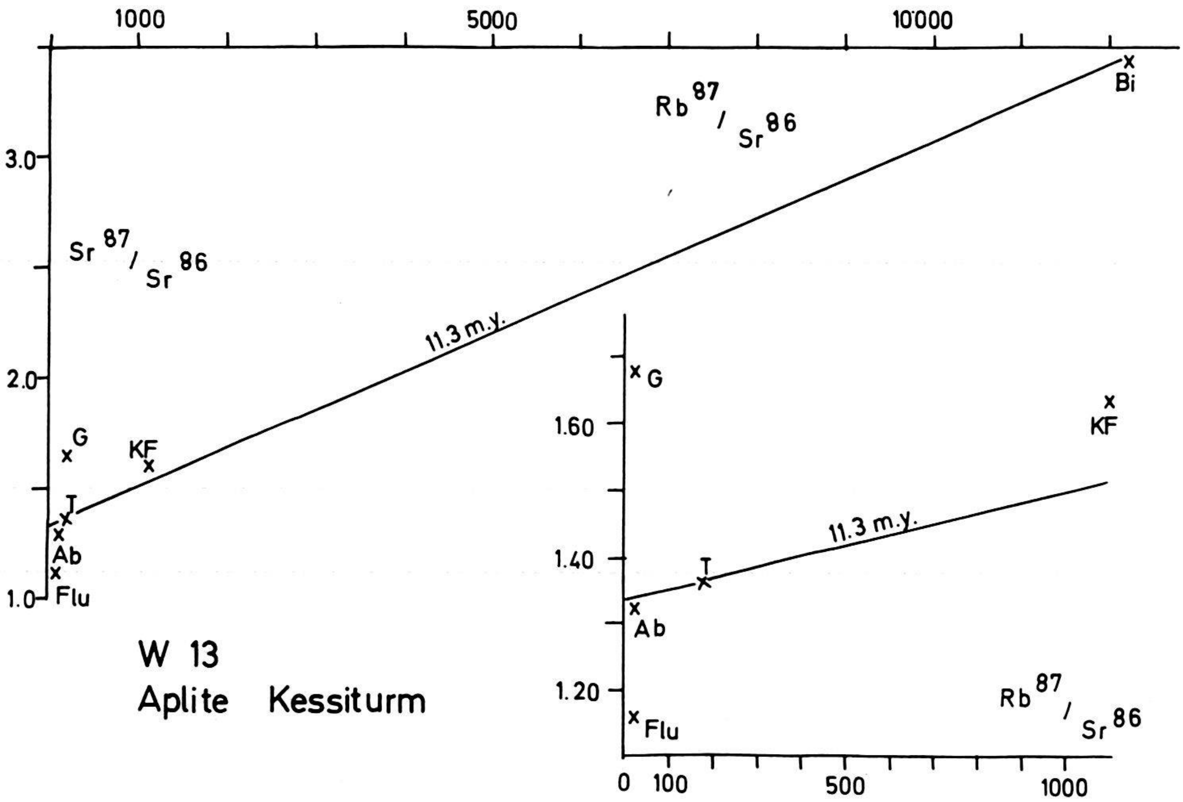

Fig. 1. Sr-evolution diagram of minerals and total rock from the Aplite Kessiturm: T = total rock, G = garnet, Flu = fluorite, Ab = Albite, KF = K-feldspar and Bi = biotite.

11.3 m.y., one of the lowest age values so far found in the Central Alps. This age is interpreted as cooling age after the last phase of Alpine metamorphism. The points for the other minerals, K-feldspar, albite, garnet and fluorite scatter in the Sr-evolution diagram. In this zone of Alpine metamorphism, stilpnomelane-chloritoid, no Sr-homogenisation was reached.

In the zone of Alpine chloritoid, phengite was formed in many rocks during the Alpine metamorphism. We frequently find pre-Alpine muscovite, which has preserved its pre-Alpine Rb-Sr age, together with Alpine phengite. Both micas often occur in the same hand specimen. In the chloritoid zone biotite may preserve its pre-Alpine age, but only in basic rocks of high resistance against metamorphism. In acid granitic rocks only young Alpine biotite ages were found. If the rock contains only phengite and no pre-Alpine muscovite Sr-homogenisation occured during the Alpine metamorphism. As an example the Rb-Sr analyses on the Rotondo granite are presented.

Figure 2 gives the Sr-evolution diagram of minerals and the total rock sample from the Rotondo granite, Gotthard massif. This rock is located in the inner chloritoid zone. The minerals garnet, epidote, and the feldspars show Sr-homogenisation, the age difference between phengite — 36.3 m.y. — and biotite — 14.5 m.y. — must be due to slow cooling. Only apatite does not fall on the young isochron. This cannot be explained by an analytical error, since three repeat analyses agree within the error limit. We cannot explain this special behavior of apatite. We do not know if the deviation from the young isochron is due to incomplete Sr-homogenisation or to a later Sr-ex-

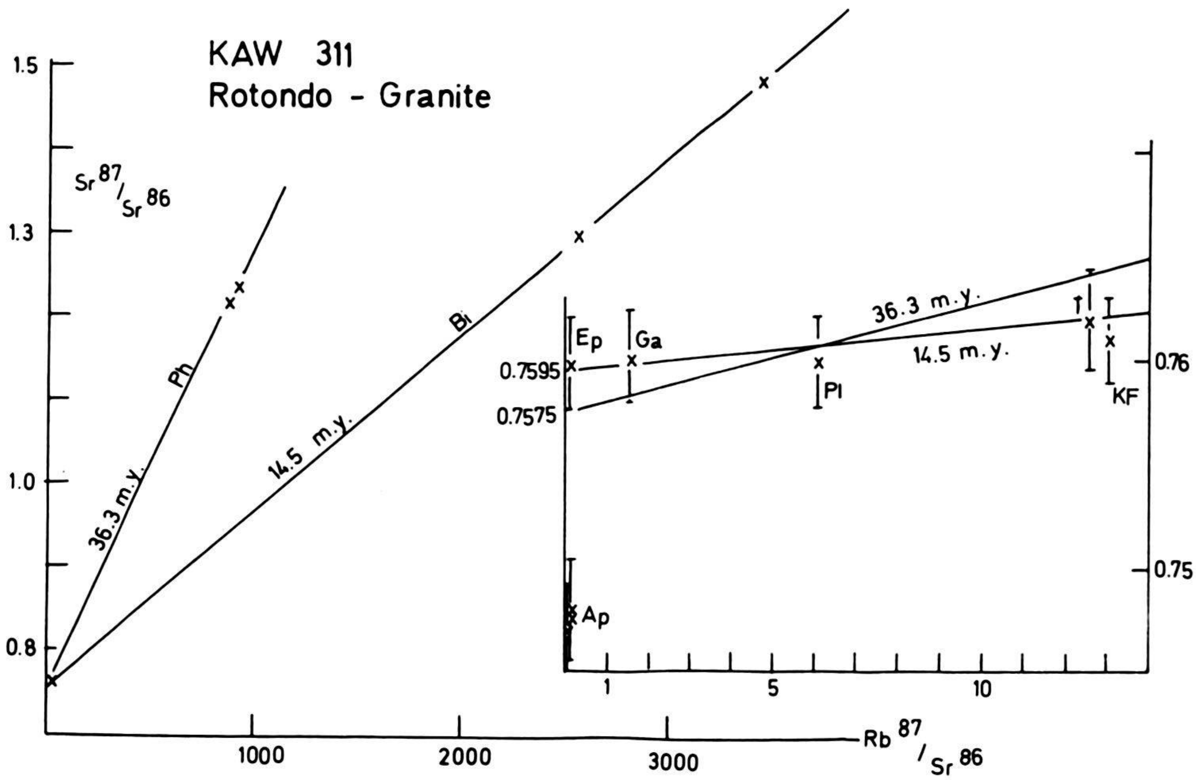

Fig. 2. Sr-evolution diagram of minerals and total rock from the Rotondo granite: T = total rock, Ep = Epidote, Ga = garnet, Ap = apatite, Pl = plagioclase, KF = K-feldspar, Ph = phengite and Bi = biotite.

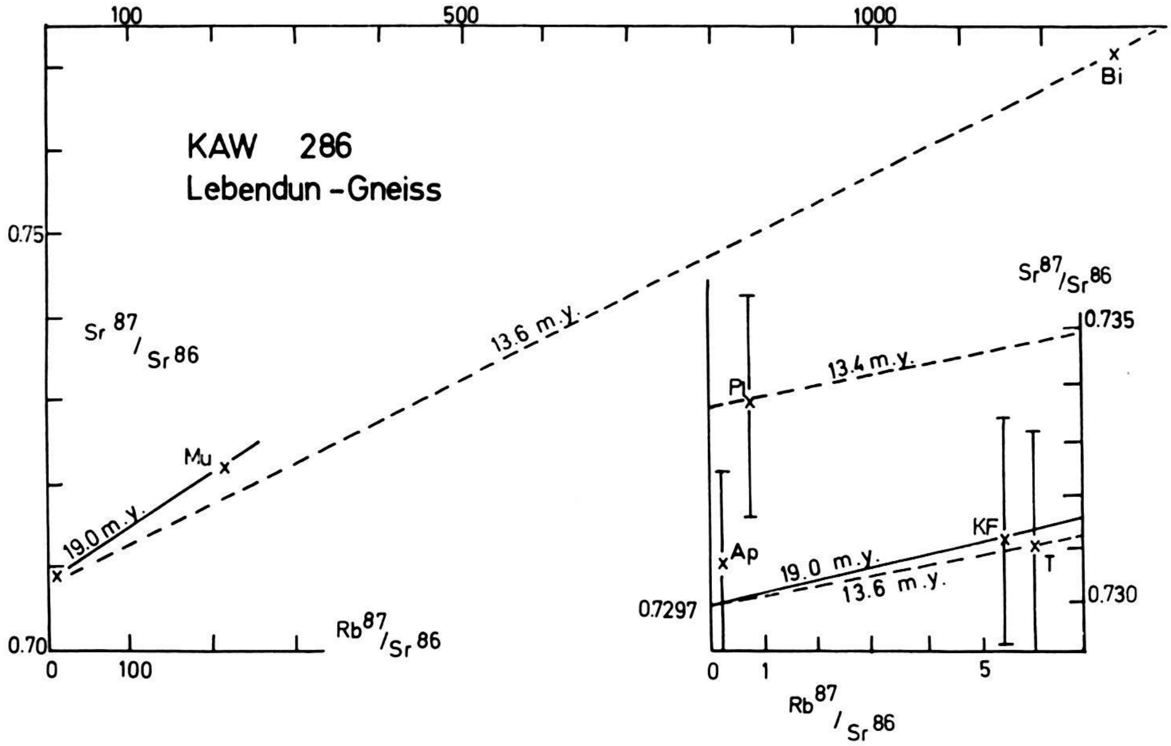

Fig. 3. Sr-evolution diagram of minerals and total rock from the Lebendun-gneiss: T = total rock, Ap = apatite, Pl = plagioclase, KF = K-feldspar, Mu = muscovite and Bi = biotite.

change process of apatite. Since apatite is very rare in this rock and has a common Sr content of only 100 ppm, such an exchange process would not show in the total rock isochron, which gave a pre-Alpine age result of 263 m.y., see E. Jäger and E. Niggli, 1964. It is further interesting to note that the feldspars as well as epidote and garnet seem to fall on the younger biotite isochron. This means that they were open systems during the cooling period down to temperatures around 300 °C. Since the difference in the inclination of the phengite and the biotite isochron is rather small, this has to be proved by further analyses.

In the zone of Alpine kyanite no pre-Alpine biotite ages have yet been found. In this zone coarse-grained muscovite can preserve its pre-Alpine Rb-Sr age, even when it is overgrown by Alpine muscovite. This was demonstrated on the I Mondei pegmatite, see G. Ferrara, B. Hirt, E. Jäger and E. Niggli, 1962.

The next sample, see Figure 3, Lebendun gneiss, comes from the northern part of the Pennine nappes, from Cascata Toce. It is also located in the zone of Alpine kyanite. The feldspars and apatite indicate Alpine Sr-homogenisation. The slight deviation of the plagioclase from the mineral isochron might be due to analytical error. The age difference between muscovite – 19.0 m.y. – and biotite – 13.6 m.y. – is explained by slow cooling. Each mica age was calculated using only the datum for the respective mica together with the data of the total rock sample and other separated minerals. Since the micas have a high Rb/Sr ratio, the selection of the total rock sample alone or together with the other minerals does not make a large age difference in the mica isochron. The biotite, calculated with the plagioclase alone, gives an age result of 13.4 m.y.

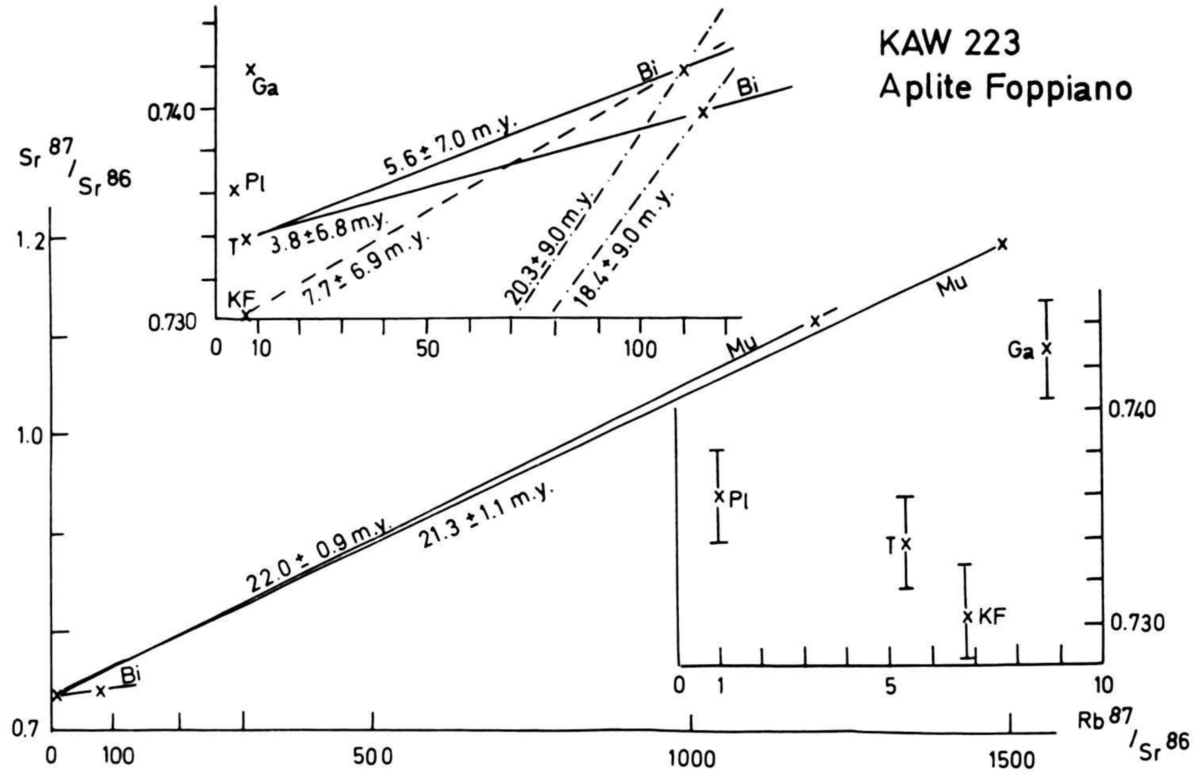

Fig. 4. Sr-evolution diagram of minerals and total rock from the aplite Foppiano: T = total rock, Ga = garnet, Pl = plagioclase, KF = K-feldspar, Mu = muscovite and Bi = biotite. The upper diagramm shows the isochrons biotite-total rock, biotite-K-feldspar and biotite-common Sr, $Sr^{87}/Sr^{86} = 0.7091$.

instead of 13.6 m.y. when calculated with the total rock and all the other minerals, except muscovite.

Figure 4 gives the Sr-evolution diagram for the minerals and total rock from an aplite dyke in the Pennine nappe area near Foppiano, south of the Lebendun gneiss. This rock is situated in a zone of a still higher grade of Alpine metamorphism than the Lebendun gneiss and the Rotondo granite. No Sr-homogenisation was found among the feldspars, total rock and garnet, although in this locality the grade of Alpine metamorphism was certainly sufficient to cause Sr-homogenisation. The aplite dyke has a diameter of only 1 m. The country rock has a Sr-content of 400 ppm, see J. C. Hunziker, 1966, while the aplite contains only 89 ppm common Sr. We assume an exchange process between the gneiss and aplite. The minerals must have incorporated variable amounts of Sr from the country rock. Next to muscovite the garnet has the lowest content of common Sr, only 2.66 ppm, but shows the highest Sr^{87}/Sr^{86} ratio, except muscovite. It must have incorporated less Sr from the country rock than the feldspars. The K-feldspar has the highest content of common Sr – 154 ppm – and shows the lowest Sr^{87}/Sr^{86} ratio, even lower than the total rock aplite value. This exchange process is also demonstrated by the mica analyses: The muscovite contains only 1.86 ppm common Sr, it cannot have incorporated much Sr from the country rock. The age values of 21.3 m.y. and 22.0 m.y. are the normal cooling ages for this area. Unfortunately the biotite is not a pure concentrate as it contains some chlorite.

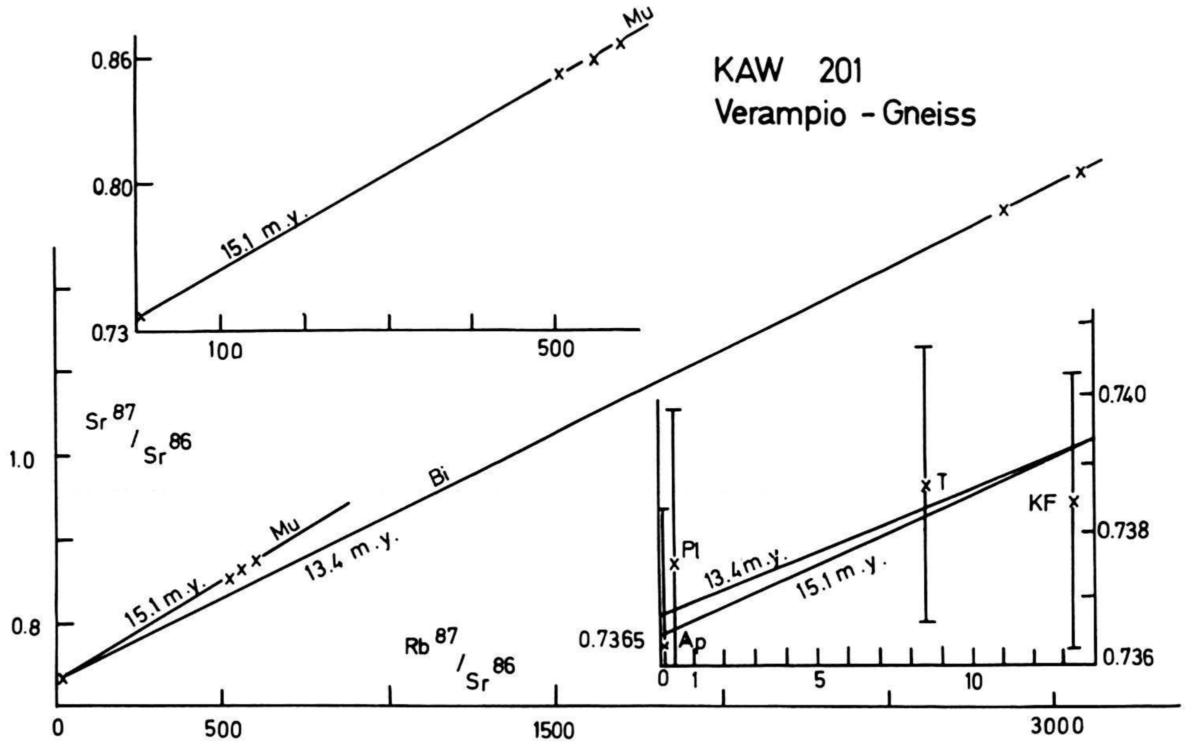

Fig. 5. Sr-evolution diagram of minerals and total rock from the Verampio gneiss: T = total rock, Ap = apatite, Pl = plagioclase, KF = K-feldspar, Mu = muscovite and Bi = biotite.

Biotite has a higher common Sr-content of 15.6 ppm. Calculated with the total rock analysis, biotite ages of 5.6 m.y. and 3.8 m.y. were found. These are much too low for the cooling ages of this region, they are generally about 13 m.y. When calculated with common Sr, Sr^{87}/Sr^{86} being 0.7091, ages of 20.3 m.y. and 18.4 m.y. were found. These are too high for the area. Calculated with the K-feldspar, which has the lowest Sr^{87}/Sr^{86} ratio of this rock, biotite gives an age result of 7.7 m.y., which seems too young, but is already within the error limit of the 13 m.y. age. To fit the biotite age to the 13 m.y. result, it must be calculated with a mixture of "common" Sr from both the dyke and the gneiss. Because of the high error limit on the biotite measurements and because of the fact that the biotite contains chlorite, the biotite results alone cannot be used as conclusive evidence of Sr exchange with the country rock. Both facts together, the anomalous biotite ages and the scatter of the mineral points in the Sr-evolution diagram point to Sr-exchange with the country rock. Certainly more analyses should be performed on this aplite dyke.

It should be mentioned that in other rocks, a content of chlorite did not influence the biotite cooling age. In one case, Fibbia granite, Gotthard massif, a good isochron was obtained between chlorite, biotite and total rock, representing the local biotite cooling age.

Gneiss samples from still higher grade of Alpine metamorphism show complete Sr-homogenisation. The gneiss from Verampio, Figure 5, gives a smaller muscovite-biotite age difference of only 1.7 m.y., compared to the 8 m.y. age difference of the other gneiss-samples around Verampio. The gneiss from Verampio forms a tectonic window, representing the deepest exposed rock of the Alps. The muscovite age of

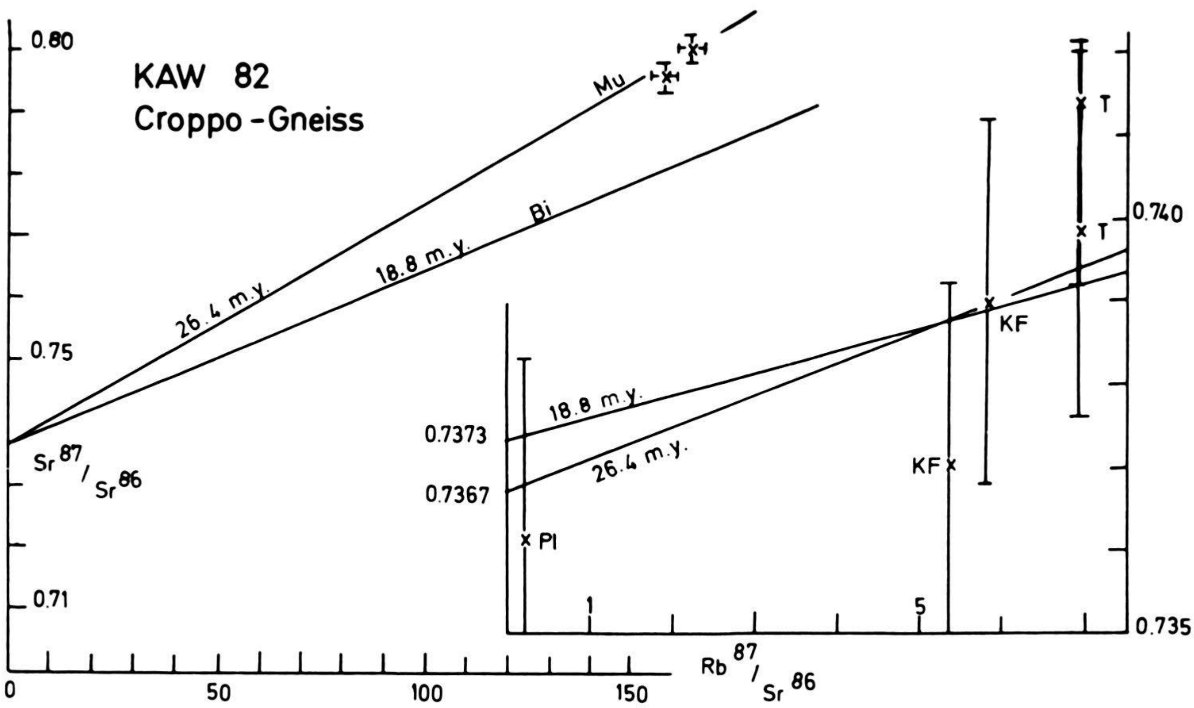

Fig. 6. Sr-evolution diagram of minerals and total rock from the Croppo gneiss: T = total rock, Pl = plagioclase, KF = K-feldspar, Mu = muscovite and Bi = biotite.

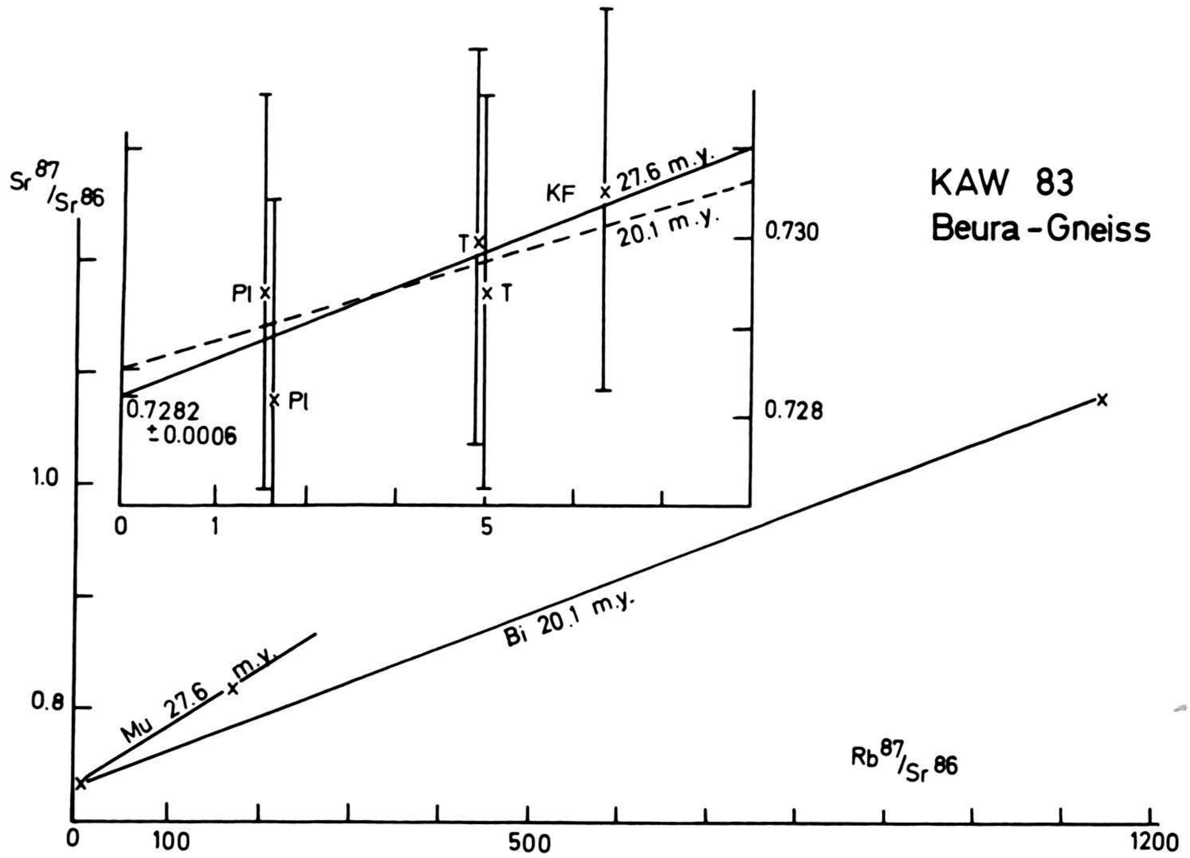

Fig. 7. Sr-evolution diagram of minerals and total rock from the Beura gneiss: T = total rock, Pl = plagioclase, KF = K-feldspar, Mu = muscovite and Bi = biotite.

15.1 m.y. is the youngest muscovite age so far found in the Alps. This young age must mean the late uplift of the anticline, the small age difference between muscovite and biotite would indicate quicker cooling, caused by the updoming.

The micas from the root zone, from the gneisses from Croppo, Figure 6, and Beura, Figure 7, give muscovite-biotite age differences of 8 m.y., as they are generally found in this area. In both rocks the feldspars show Sr-homogenisation.

In all the samples, except the phengite from the Rotondo granite, the mica ages represent cooling ages. In the Rotondo granite the age difference between phengite and biotite is 22 m.y. We assume that in the zone of Alpine chloritoid the temperature was not sufficiently high to cause rejuvenation of the phengite after its formation. The phengite must have crystallized near the maximum temperature of the younger phase of Alpine metamorphism. This age therefore dates the formation of phengite and the phase of metamorphism and not a cooling stage after the metamorphism. The temperature was sufficient in the Rotondo granite to keep the biotite as an open system for Rb-Sr for more than 20 m.y. The young biotite ages date the cooling to about 300 °C.

This means that in the outer zone of metamorphism we have the chance to date the time of the metamorphic phase by the formation of phengite or muscovite. On these minerals in the western, northern and eastern zone surrounding the area of higher grade of metamorphism ages of 36–38 m.y. were found, see also J. C. HUNZIKER, 1969. This value corresponds well with the geological evidence, with a phase of metamorphism near the boundary Eocene-Oligocene.

Biotite dates always a cooling age. It is formed at higher temperatures than is muscovite, but the closed system for Rb and Sr is reached at much lower temperatures during the cooling period. An old biotite Rb-Sr age cannot be preserved when new biotite is formed.

Total Rock Systems

Rb-Sr analyses on total rock samples from the Central Alps generally give pre-Alpine age results. Several age groups can be distinguished in the range from 240 to 430 m.y. So far, age results of more than 400 m.y. have been found only in the Austroalpine nappes, in the Silvretta and the Oetztal, and not in the Pennine nappes. In the Pennine region of the Central Alps and in the Pennine Tauern window total rock ages of 240 m.y., 270 m.y. and 300 m.y. were found, in the Central Alps also ages around 350 m.y. For these dates see: J. C. HUNZIKER, this volume, R. ST. J. LAMBERT, 1964, C. BESANG, W. HARRE, F. KARL, H. KREUZER, H. LENZ, P. MÜLLER and I. WENDT, 1968, J. C. HUNZIKER, 1969 and O. SCHMIDEGG, 1969. and E. JÄGER and F. KARL, Austroalpine nappes: B. GRAUERT, 1966, K. SCHMIDT, E. JÄGER, M. GRÜNENFELDER and N. GRÖGLER, 1967, and W. HARRE, H. KREUZER, H. LENZ, P. MÜLLER, I. WENDT and K. SCHMIDT, 1968.

During the Alpine metamorphism all these ages were preserved, indicating that all the rocks were closed systems for Rb and Sr. This is true even for the highly recrystallized gneisses from the Ticino area, which occur within the stability range of Alpine kyanite.

Young Rb-Sr total rock ages were found only in pegmatites which cut the Alpine gneissic structure of their country rocks and on the Novate granite, which is a late acid variety of the Tertiary Bergell intrusion. The Bergell granite clearly cuts Alpine structures. There is no doubt that both rocks, the pegmatites and the Bergell granite, represent late Alpine formations. In these examples the young Rb-Sr total rock ages correspond with the geological evidence.

Under special conditions pre-Alpine rocks acted as open systems for Rb-Sr during the later metamorphism:

1) As mentioned above inhomogeneous rocks, such as small aplite dykes and their country rocks were involved in Rb-Sr exchange processes. This process has been shown so far for two aplite cases, occuring only over distances of several meters.

2) In the front part of Pennine nappes Rb-Sr total rock isochrons in the range of 110 to 125 m.y. have been found; see G. N. HANSON, M. GRÜNENFELDER and G. SOPTRAYANOVA, 1969, J. C. HUNZIKER, this volume, and E. JÄGER, J. C. HUNZIKER and S. GRAESER, in preparation.

In the same rocks from the interior part of the nappes pre-Alpine total rock ages were preserved. The special conditions which distinguish the front part from the interior part of the nappes are the contact to sedimentary rocks, and intensive fracturing and deformation. We do not know, if these young ages mean an exchange process between gneiss and the sedimentary calcareous schists, or if they mean a homogenisation process mainly within the gneiss. High initial Sr^{87}/Sr^{86} values (0.730 in the case of the Roffna-gneiss, G. N. HANSON et al., 1969) indicate that most of the Sr involved in this homogenisation process must have come from the gneiss itself.

If this homogenisation process was caused by fracturing which opened channels allowing fluid streams from the sedimentary rocks to flow through the gneiss, this would mean a possibility of dating early movement phases in the Alps. This homogenisation process acted over a larger distance in the range of 100 meters up to several km.

3) In the Pyrenees a partial redistribution of Rb-Sr in total rocks was described by E. JÄGER and H. J. ZWART, 1968. In gneisses of similar chemical composition, only those rocks which showed fine grained structures, preserved their pre-metamorphic age of 475 m.y.

Augengneisses, which grade into rocks of granitic structures, show deviations from this original 475 m.y. isochron. They scatter around a new 300 m.y. isochron. Partial Sr-redistribution is found in rocks which show mobilization and partial anatexis. The rock which has the largest deviation from the 475 m.y. isochron is the largest granite body in the area studied. This effect of partial Sr-redistribution caused by the Hercynian metamorphism must have acted over distances of several km.

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