daher häufig nur als flache, verzerrte und unbestimmbare Reste vor. Nur einzelne Exemplare waren wenigstens generisch mit einiger Sicherheit bestimmbar. Dabei ergab sich u. a. das Auftreten von *Zaphrentites*? sp., *Siphonophyllia* sp., „*Caninia*" sp., *Amplexus* sp., *Michelinia megastoma* PHILLIPS? und *Aulopora* sp. Die beiden erstgenannten Genera sind im Unter-Karbon leitend, wobei *Siphonophyllia* McCOY vor allem im höheren Unter-Karbon auftritt.

Die Fauna des höheren Perm umfaßt *Plerophyllum (Plerophyllum)* n. sp., *Wannerophyllum* n. sp., *Gertholites curvata* (WAAGEN und WENTZEL 1886). Vielleicht gleiches Alter besitzen Schichten mit *Plerophyllum (Ufimia)* sp. und *Polycoelia (Polycoelia)* cf. *profunda* (GEINITZ). Das Dominieren von Gattungen der Familie Polycoelidae ist eine charakteristische Eigenheit höherpermischer Korallenfaunen, wie das Beispiel Djulfa (armenische SSR) zeigt.

Isotopic Age Determinations on Gneisses from the Tauernfenster, Austria

By R. ST. J. LAMBERT*)

With 2 Figures

Absolute Altersbestimmungen an Gneisen aus dem Tauernfenster

Von R. ST. J. LAMBERT

Mit 2 Abbildungen

Zusammenfassung

Gesteinsproben von Granitgneisen des Zentralgneiskomplexes des Hochalm-Ankogel-Massivs — einer der Gneiskerne im Tauernfenster — wurden auf ihren Rubidium-Strontium-Gehalt untersucht; dies ergab ein Alter von 243 ± 11 Mill. Jahren (Mittleres Perm) und ein ursprüngliches Sr^{87}/Sr^{86}-Verhältnis von 0.7113 ± 0.0025 für die Intrusion der Granite, welche jetzt den Gneiskomplex bilden. Eine Rekristallisation der Gesteine vollzog sich vor 20 ± 10 Mill. Jahren. Das Studium der Altersverhältnisse auf Rb/Sr-Basis der Granosyenitgneise — als Teil der Gesamt-Gneise — gibt keinen Anhaltspunkt dafür, ob diese ebenfalls zum Hercynischen Anteil des Gesteinsbestandes gehören oder ob sie später gebildet wurden. Die Granosyenitgneisgruppe, von welcher bekannt war, daß sie sich chemisch von den übrigen Gneisen unterscheidet, ergab ein niedriges Rb/Sr-Verhältnis, und zwar etwa 3mal niedriger als jenes der Granitgneise, ein Unterschied, der statistisch bedeutungsvoll erscheint.

Abstract

Rubidium-strontium studies on whole-rock samples of granitegneisses from the Central Gneiss complex of the Hochalm-Ankogel massif, one of the gneissic cores in the Tauernfenster, give an age of 243 ± 11 m. y. (Middle Permian) and an initial Sr^{87}/Sr^{86} of 0.7113 ± 0.0025 for the intrusion of the granites which now form the gneiss complex. Recrystallisation of the complex occurred 20 ± 10 m. y. ago. Rb-Sr age studies on the granosyenite-gneiss group, a unit of the gneiss complex, cannot be used to determine whether it also belongs to the

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Hercynian part of the complex or was formed later. The granosyenite-gneiss group, known to be chemically distinct from the remainder of the gneisses, was found to have a mean Rb/Sr ratio about three times smaller than that of the granite-gneisses, the difference being statistically significant.

Contents

I. Introduction

The Tauernfenster, lying in the middle of the exposed Alpine range in Western and Central Austria, consists of two major units, the Central Gneisses and the Schieferhülle, together with subordinate units associated with the Central Gneisses. The Central Gneisses form the gneissic cores of a series of major domal structures, of which the one studied (the Hochalm-Ankogel massif) is the most easterly. This gneissic core was chosen for study on account of the excellent petrological and geological information available for the district of Badgastein (Exner, 1957), together with a 1 : 50,000 geological map. Further reasons for choosing this area include the suitability of the rock units for isotopic age studies, the ease of access, and the possibility of collaboration with the structural and metamorphic studies being carried out in the adjoining area to the south-east by E. R. Oxburgh, also of Oxford University.

The controversy over the origin and history of the Tauernfenster has been clearly set out by Exner. Essentially, two main theories have been held:

1. that the gneiss cores are Hercynian (Variscan) granitic intrusives, converted to granite-gneisses during the Alpine orogeny, whereas their schist cover, now apparently conformable with the gneisses, consists of a parautochthonous series of Mesozoic sediments;

2. that the gneiss cores are essentially of Tertiary (Alpine) origin, having been formed by some form of granitisation process.

The recent developments which have taken place in isotopic age studies using variations in the isotopic composition of Sr in "whole rocks" and their individual minerals, following the work of the Bernard Price Institute, Johannesburg (Nicolaysen, 1961), have made problems such as the one considered here amenable to solution. From one set of analyses of samples of "whole rocks" it may be possible to find the time and mode of origin and (if individual minerals are analysed) to date the latest recrystallisation of the rocks, if metamorphosed.

II. Collection and preparation of specimens

All specimens were collected by the author during 1961 and 1962. In 1961, in a preliminary visit to the area with E. R. Oxburgh, a representative series was collected, of which one (2093) was subsequently analysed. After discussing the problem with members of the Austrian Geological Survey and others during a Geological Survey excursion in 1961, further field studies and collection were made in the vicinity of Badgastein and Mallnitz during 1962.

Preliminary studies based on the work of Exner indicated that the gneisses of the Hochalm-Ankogel massif consist of a number of mappable units collectively referred to as the Central Gneisses, one of which, the granosyenite-gneiss, is sufficiently distinct from the rest to be separated on the 1 : 50,000 map. Examination of the granosyenite-gneiss group suggested that it might have had a different history from the rest of the complex, so particular efforts were made to study its field relations, petrography and Rb-Sr geochemistry. In the following, specimens from all other types of the Central Gneisses are referred to collectively as Central Gneiss, but the granosyenite-gneiss is distinguished by that name.

Field observations show that principal units within the Central Gneisses (augen-gneisses, biotite-muscovite-gneisses without augen structure, forellen-gneiss) usually occur in mappable units 100 m or more thick of considerable areal extent (for example, the forellen-gneiss occupies an area 10 by 3 km). In choosing representative rocks, marginal parts of each unit were avoided as far as possible, and only the freshest material collected from the inner parts of each unit. The granosyenite-gneisses proved to be more difficult to sample in this manner, since although some units are very thick, as in Nassfelder Tal, others are highly attenuated. The latter occur in close proximity to the Schieferhülle at a boundary where marked attenuation of both schists and gneisses occurs, and where the gneisses are frequently converted to muscovite-quartz-schists (Exner, 1957, pp. 111—113). Individual hand specimens were chosen for representativeness, and were usually about 500 cm^3 in size, although larger specimens were taken from the coarser augen-gneisses.

After a preliminary hand specimen and thin section study, thirty specimens were chosen and the greater part of each crushed to a maximum grain size of about 0.3 mm, taking considerable care to avoid contamination of, or loss from, the sample. A 10 gm aliquot was taken from this thoroughly homogenised powder. The 10 gm aliquot was then crushed in a porcelain ball mill for one hour, after which the maximum grain size was usually about 0.08 mm. This powder was used for the preparation of tablets for X-ray fluorescence (X. R. F.) analysis and for Rb-Sr analysis by isotope dilution.

Mineral separations from specimen 2093 were carried out by conventional magnetic and density methods.

III. Rubidium and strontium analyses

A preliminary survey of the whole-rocks was made in order to determine which specimens were most suitable for isotopic analysis. Duplicate borax-backed tablets were prepared and the Rb and Sr contents found by X. R. F. analysis using standard Philips equipment and procedures. With a tungsten tube at 750 w, using the scintillation counter and discriminator, counts of up to 3000/min were obtained, the peak to background ratio averaging 3 : 1 for this set of samples. Standard tablets were scanned in a proportion of one standard to three unknowns, the standards used being G-1 and local standards for which Rb and Sr had been obtained by isotope dilution analysis. From these standards Sr and Rb/Sr for the unknowns was obtained by direct linear comparison with the standards and Rb then found by calculation. All standards and unknowns were of approximately granitic composition.

The final figures for Rb and Sr are given in Table 1. In this table, isotope dilution figures for Rb and Sr are given where available; otherwise Sr is as found by X. R. F. analysis. All other Rb figures, where no isotope dilution

Table 1. Rb-Sr values from the Central Granite-Gneiss and Granosyenite-Gneiss of the Badgastein and Mallnitz areas

Specimen Number	Locality	Rb ppm	Sr ppm	Rb Sr
Central granite gneiss				
2093	Bockstein	159[1])	535[1])	0.297
2221 A	Nassfelder Tal	123	950	0.129
2227	Anlauftal	253[1])	135	1.87
2228	Anlauftal	256	130	1.97
2234	Nassfelder Tal	290[1])	110	2.64
2245	Bockstein	386[1])	40	9.65
2274	Lisgelespitz	314[1])	70	4.54
2275	Lisgelespitz	142	260	0.546
2279	Mindener Hutte	265[1])	115	2.30
2280	Mindener Hutte	245[1])	25	9.81
2291	SW of Mallnitz	138	470	0.293
2298	SW of Mallnitz	342	420	0.814
Modified Central granite gneiss				
2226	Anlauftal	200	90	2.22
2246	Stubnerkogel	200	545	0.366
Granosyenite gneiss				
2221	Nassfelder Tal	138	900	0.153
2229	Radhausberg	161	930	0.173
2230	Radhausberg	304	740	0.410
2232	Radhausberg	133	860	0.154
2236	Nassfelder Tal	81	950	0.085
2237	Nassfelder Tal	57	630	0.090
2244	Bockstein	109	820	0.132
2251	Nassfelder Tal	157	990	0.158
2255	Flug Kopf	123	560	0.219
2263	Gross Arl Tal	323	540	0.598
2297	SW of Mallnitz	328	840	0.390
2303	SW of Mallnitz	318	780	0.418
2304	SW of Mallnitz	323	760	0.425
Late aplite				
2273	Obervellach	223	300	0.743

figure is available, have been calculated from the X. R. F. Rb figures by subtraction of 5% (the X. R. F. results for Rb were consistently 5% too high by comparison with subsequent isotope dilution results on the same material) and the Rb/Sr ratios calculated subsequently.

It is clear from Table 1 that the granosyenite-gneisses are richer in Sr than the remaining gneisses, having such high Sr/Rb ratios, indeed, that no information concerning their age can be obtained using present mass-spectrometric methods. The distinctiveness of the granosyenite-gneisses is demonstrated in Figure 1, a frequency diagram of Rb/Sr ratios obtained by plotting the frequency

[1]) Rb and Sr figures obtained by isotope dilution: all other figures by XRF analysis. All Sr figures quoted to nearest 5 ppm; errors estimated at 5% for XRF data.

of occurrence of ratios of $\log_{10}$ (Rb/Sr) for class intervals of 0.33. The mean Rb/Sr ratios of the two groups are significantly different at the 95% confidence level. This difference in Rb/Sr corresponds well to the differences in major

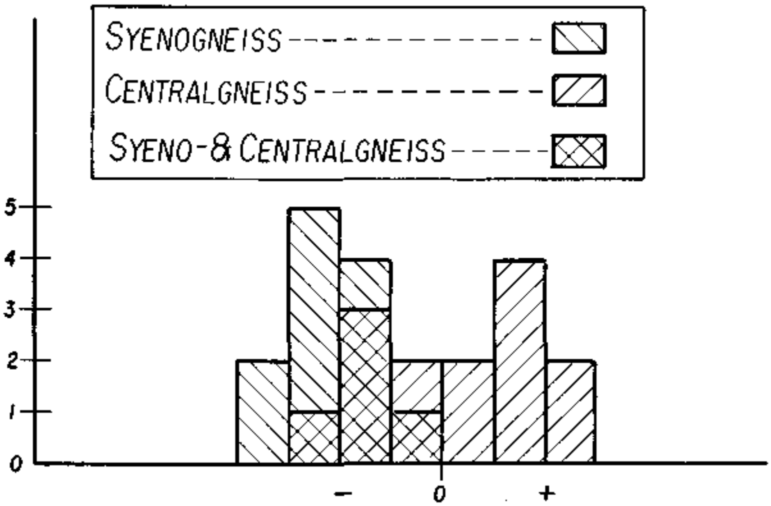

Figure 1. Frequency diagram of Rb/Sr ratios in the Central Gneisses and the granosyenite-gneiss group. Plotted in class intervals of 0.33 $\log_{10}$ Rb/Sr.

element contents given by EXNER (1957, pp. 78 and 119) where analyses of typical Central Gneisses (Nos. 1, 2, 5, 7 and 8) average CaO = 1.40%, K_2O = 4.13% and a granosyenite-gneiss (No. 9) has CaO = 4.03%, K_2O = 7.18%.

It may also be observed from Table 1 that the granosyenite-gneisses appear to be more homogeneous than the remainder of the gneisses sampled. An undeformed aplite vein from Obervellach, presumably younger than the formation of the gneisses, proved to be unsuitable for age determination.

IV. Isotopic age determinations; analytical procedure

From the thirty specimens available, ten were chosen for mass spectrometric analysis in addition to 2093, analysed prior to the 1962 collecting season. The analyses were carried out on an MS. 5 mass spectrometer using the standard Oxford procedures as stated in GILETTI et al. (1961), modified by L. E. LONG and E. HAMILTON. The principal modifications include the use of tantalum sinter on the tantalum filament, the use of improved ion-exchange column techniques and the prior calculation of the quantity of internal standard required to give the least error in the Rb and Sr analyses. All calculations of the isotope ratios and errors were carried out by the Oxford Mercury computer. The quoted errors (all at 95% confidence level) are those arrived at by calculation alone and do not include possible errors due to bad sampling, geochemical alteration (weathering), inexact chemical preparation (except that an allowance for Rb or Sr blank is made in each analysis) or any error in the half-life of Rb^{87} (taken as 4.7×10^{10} years). The Rb and Sr internal standards employed contained 90.24% Rb^{87}, and 0.06% Sr^{84}, 81.81% Sr^{86}, 4.23% Sr^{87} and 13.90%

Sr^{88}, respectively, the errors on these atomic abundances being approximately 0.3%. The quoted Sr^{87}/Sr^{86} values were all obtained by direct measurement of sample Sr without use of internal standard („unspiked"), the ratio 87/86 in Table 2 being obtained from the measured 87/86 by multiplication by the factor $(\alpha + 1)$ 1/2 where α, the fractionation, is (88/86 observed) 0.1194, 0.1194 being the normally accepted Sr^{86}/Sr^{88} ratio. A correction for fractionation in the analyses for Sr using an internal standard („spiked") was made (using the computer) by employing an equation containing the four ratios unspiked 88/86 and 87/86, spiked 88/86 and 87/86, together with the four unknowns, 87/86 in the sample today, Sr content of sample, and α_u and α_s, the two fractionations in the unspiked and spiked mass spectrometric analyses. This procedure was employed to reduce to a minimum the calculable error, necessitated by the comparatively young age of the samples.

V. Isotopic age determinations; discussion of results

The results are given in Table 2 and illustrated in Figure 2, a plot of Sr^{87}/Sr^{86} today versus Rb^{87}/Sr^{86} (Nicolaysen, 1961): the analysed samples are briefly described in the Appendix.

In considering the interpretation of the results it is necessary to remember that the age of a rock or mineral can be calculated only if the quantity of Rb and Sr in the phase now and the isotopic composition of the Sr both now and at the time of formation of the analysed phase are known. The age so calculated represents the time since the phase became a system closed to Rb and Sr, assuming that this equals the "age of formation". If the initial 87/86 is not known, the calculated age will not, in general, equal the time since the phase became a closed system (the "age" in common geological use).

For any individual sample of rock it is impossible to determine both its age of formation and initial 87/86, but a set of cogenetic rocks may be so used. It is necessary to assume that in such a system, all rocks began their history in their present chemical form with the same initial 87/86. This is likely to be true if the series of rocks are comagmatic: it was with this in mind that the Central Gneisses were selected for study, because the published accounts of these rocks clearly demonstrate their granitic nature and magmatic affinities.

The results from the Central Gneisses confirm this assumption, as may be seen in Figure 2. Of the seven analysed gneisses, five lie almost perfectly on a straight line (isochron), which they should do if the cogenetic and closed system requirements are met. The slope of the line is proportional to the age (243 ± 11 m. y.) and the intercept at $Rb^{87}/Sr^{86} = 0$ (0.7113 ± 0.0025) is the initial Sr^{87}/Sr^{86} of the system.

The two Central Gneisses not lying on the isochron of Figure 2 (2279 and 2280) are related geographically and possibly genetically. The coarse K-feldspar augen gneiss (2279) is representative of a large volume of such rocks northeast of the Mindener Hütte, but 2280 is a muscovite-rich feldspar-poor gneiss of phyllonitic type and is probably derived from the nearby augen gneiss during the Alpine earth movements (as described by Exner for other examples of this rock type, pp. 111—113, 1957). It is impossible to calculate an exact age for 2280, but a maximum age of 75 m. y. and a probable upper limit of age of 45 m. y. can be calculated using 2093 and 2279 as parental rock types respectively. It should be possible, with further analyses of such rocks, to establish a definite age for their formation, but the information so far obtained only

Table 2. Isotopic Data

Sample No.	Locality	Rb ppm	Sr ppm	87/86 today*)	α 88/86$_s$	α 88/86$_u$	Rb^{87}/Sr^{86}
Whole rock Centralgneiss							
2093	Bockstein	159 ± 3	535 ± 15	0.7138 ± 0.0046	1.0095	1.0021	0.86 ID
2227	Anlauftal	253 ± 5	—	0.7298 ± 0.0024	—	0.9982	5.09 XRF
2234	Nassfelder Tal	290 ± 6	110 ± 2	0.7385 ± 0.0019	0.9849	0.9973	7.63 ID
2245	Bockstein	386 ± 8	42.4 ± 0.5	0.8056 ± 0.0014	—	0.9956	26.4 ID
2274	Lisgelespitz	314 ± 6	67.7 ± 0.7	0.7591 ± 0.0017	—	1.0016	13.4 ID
2279	Mindener Hütte		—	0.7298 ± 0.0020	—	1.0032	6.34 XRF
2280	Mindener Hütte		26.4 ± 0.5	0.7449 ± 0.0020	0.9931	0.9968	26.9 ID
Whole rock Granosyenitegneiss							
2236	Nassfelder Tal	—	—	0.7102 ± 0.0031	—	0.9891	0.25 XRF
2251	Nassfelder Tal	—	—	0.7166 ± 0.0031	—	0.9910	0.45 XRF
2303	Mallnitz	—	—	0.7176 ± 0.0030	—	0.9949	1.18 XRF
2263	Gross Arl Tal	—	—	0.7164 ± 0.0020	—	0.9926	1.75 XRF
Minerals from 2093							
2093	Biotite	744 ± 9	104 ± 3	0.7201 ± 0.0022	1.0062	0.9990	20.8 ID
2093	Muscovite	398 ± 4	67 ± 3	0.7155 ± 0.0025	—	0.9958	16.4 ID
2093	K-feldspar	46 ± 2	240 ± 5	0.7116 ± 0.0018	—	1.0025	0.53 ID

*) All 87/86 values were measured directly and have been normalised to an 88/86 of 8.3572. % error in 87/86 = % error in 87/86 observed + 1/2 (% error in 88/86 observed).

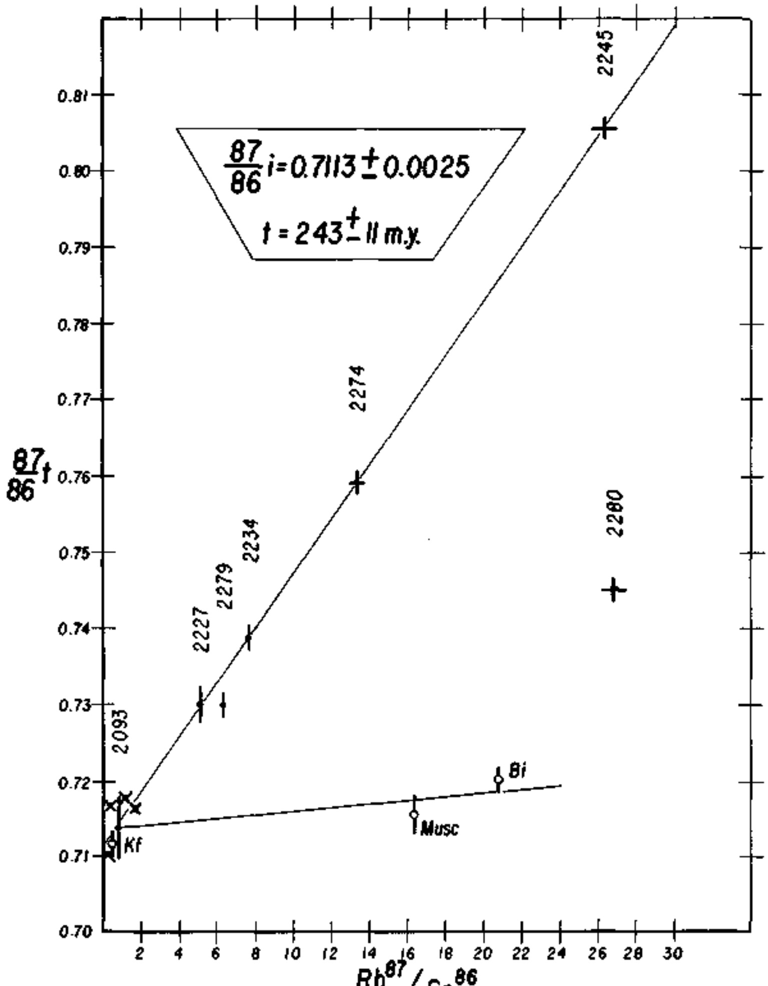

Figure 2. Graph of Sr^{87}/Sr^{86} today against Rb^{87}/Sr^{86} for all isotopically analysed specimens. ● = whole rock Central Gneisses, O = minerals from 2093, x = whole rock granosyenite-gneisses. Vertical and horizontal dashes indicate analytical uncertainty. For all mineral samples and the whole rocks with lower Rb/Sr, the error in Rb/Sr has been omitted, as it is quantitatively insignificant.

suggests that these phyllonitic gneisses were produced during the Tertiary earth movements. The alternative explanation, that this is a truly Hercynian rock, chemically modified by diffusion of Sr^{87} during the Alpine metamorphism is not likely in view of the fact that muscovite is known to retain radiogenic Sr^{87} to a high degree, even during substantial metamorphic events. The Alpine metamorphism in this area was probably in the epidote-amphibolite facies (EXNER, 1957, pp. 153—154). For the time being, it is thought that during the Alpine metamorphism, the parent augen-gneiss of 2280 recrystallised with segregation of muscovite and quartz, and solution of the ferromagnesian and feldspar minerals during a period of intense deformation. The newly formed muscovite began its history with a high radiogenic Sr^{87} content, giving an apparent age greater than the age of metamorphism. A mild version of this process may have affected 2279, reducing its apparent age by about 10%, but there is nothing about the petrography of 2279 to suggest any exceptional history.

Four specimens from the granosyenite-gneiss group, with as high Rb/Sr as any found, were analysed for the isotopic composition of their Sr only; the results are plotted in Figure 2, using the X. R. F. Rb/Sr ratio. They cluster about the isochron in a fashion which suggests that the isotopic composition of Sr within this group is the same as that in the Rb-poor members of the Central Gneisses. No age can be calculated from this data and it is thought that it will be impossible to ascertain the age of the granosyenite-gneiss group by this method, using present techniques.

For a preliminary examination of the age of the metamorphism of the gneisses, specimen 2093 from the well-defined group of augen-gneisses which forms cliffs along the west side of the valley between Bockstein and Badgastein was chosen. Unfortunately the separated minerals had high Sr contents so that the measurement of their age could not be made accurately. In the absence of other separated minerals, however, it was decided to analyse these micas and the K-feldspar from the augen, in order to obtain an approximate value for the age. The results are given in Table 2 and Figure 2. No reasonable age can be calculated unless a negligible error is assumed for the present Sr^{87}/Sr^{86} of the whole rock. Even so the age is 20 ± 10 m. y., determined using both micas jointly. The K-feldspar is so rich in Sr that the isotopic analysis merely serves to confirm the isotopic composition of the Sr in the whole rock.

VI. Conclusions

The date for the recrystallisation of the micas in the typical augen-gneiss 2093, 20 ± 10 m. y., agrees with the ages of 16 to 21 m. y. obtained for many micas from the western parts of the Alps by Jäger and Faul (1959) and Jäger (1962). It suggests, but does not prove (because of analytical uncertainty) that the phase of Miocene tectonic activity which affected the western Alps also affected the Tauernfenster. This is to be expected on general geological grounds.

The age of formation of the gneisses in their present form as chemical systems presents greater difficulties. The age of 243 ± 11 m. y. indicates formation (that is, magmatic crystallisation) during the Middle Permian (Kulp, 1961: note that the uncertainty in the time-scale and in the 243 m. y. figure make either a Lower or Upper Permian age possible).

From petrological and geological studies Exner (1957) and the existing isotopic ages on the petrologically similar Baveno granite (Jäger and Faul [1959]: age revised slightly by Jäger [1962]), an age of 270 m. y. and not 243 m. y. would be anticipated for the Central Gneisses. Further, both Jäger (1962) and Krummenacher and Evernden (1960) have reported apparent ages of crystallisation of micas from the western Alps over the age range 266—292 m. y. An age of 270 ± 10 m. y. for the gneisses would also agree with local geological evidence, for the lowest Schieferhülle is thought to contain Upper Carboniferous and Permian strata resting on a former erosion surface of granite.

It is not impossible that the rocks analysed could have been formed 270 m. y. ago and completely recrystallised at 243 m. y. ago, or partly recrystallised at a later time, but either of these processes would require such a coincidental movement of Rb and/or Sr atoms (in order to produce the straight insochron of Figure 2) that neither is considered to be at all likely. Further analyses are needed to confirm the isochron, but it is felt that the evidence for formation of the parent granites at 243 m. y. is strong enough without confirmation.

Mineral ages of the order of 243 m. y. from other parts of the Alps have been reported by KRUMMENACHER and EVERNDEN (1960) and KRUMMENACHER, EVERNDEN and VUAGNAT (1960). Two of these ages, 237 m. y. for a muscovite from an aplitic granite of the Aiguilles Rouges, and 245 m. y. for a phlogopite from an ultramafic body in the Ivrea Zone, were interpreted as modified Hercynian age, but the third, 225 m. y. for the Granite de Vallorcine, Aiguilles Rouges, could have been a real age. One further Permian age, of 218 m. y., has been reported by HAHN-WEINHEIMER, e t a l. (1963) for the Barhälde-Granite of the Southern Black Forest, a supposed "Hercynian" intrusive.

Pending further work on this problem, the author would support the reality of the age of 243 ± 11 m. y. found for the initial formation of the Central Gneisses of the Hochalm-Ankogel massif. It is interesting to note that this age fits into the interval of pre-Triassic erosion mentioned by EXNER and is, to that extent, in accord with the geological evidence.

Finally, any possibility that there has been any major re-distribution of elements in the Central Gneisses during the Alpine orogeny, by "granitisation" or any similar process, may be excluded from further consideration.

VII. Acknowledgements

The author wishes to thank Dr. H. KÜPPER and members of the Geological Survey of Austria for their kindness in permitting this work, for their assistance and advice on problems of Austro-Alpine geology and for the financial assistance for field-work. Thanks are also due to Drs. L. E. LONG, M. H. DODSON, E. HAMILTON and N. J. SNELLING for their instructions and advice on analytical techniques, to Miss J. DUNSDON and Mr. D. INSKIP for sample preparation, to Mr. F. DIMITROV for draughting the illustrations and Miss SHEILA BAKER for typing the manuscript. This work was carried out as part of the programme of isotopic age research being carried out in the Department of Geology, University Museum, Oxford under the direction of Professor L. R. WAGER.

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IX. Appendix

Localities and descriptions of isotopically analysed specimens

2093

Foot of cliffs 400 m west of Pension Sonnblick, Bockstein. A typical leucocratic augen granite-gneiss with 8 mm microcline crystals set in an 0.2 mm aggregate of microcline, quartz and albite. Muscovite, biotite and iron-epidote occur principally in thin foliae. Accessory sphene and apatite. The large microclines are weakly perthitic and belong to an older generation of crystals, being broken down at their margins to form part of the quartzofeldspathic aggregate. Texture schistose, with gneissic banding weakly developed. Biotite fresh, occurring with muscovite.

2227

200 m at 300° from Hohkarfall in Anlauftal. A typical leucocratic augen granite-gneiss occurring as a 2 m band in a series of similar gneisses without augen. Similar to 2093, but the K-feldspar shows variable (optical) triclinicity, has relic Carlsbad twins, and shows semi-complete exsolution of albite. Accessory garnet (rare) and minor chloritisation of biotite are found.

2234

Quarry on south side Nassfeldertal, 150 m east of Evianquelle W. H. and 20 m south of road. A typical leucocratic biotite granite-gneiss with rare microcline "augen" up to 4 mm set in a groundmass of microcline, albite and quartz up to 0.6 mm grain-size. Rare albite crystals reach 1 mm. Biotite commoner than iron-epidote, muscovite rare: skeletal garnet fragments occur with accessories, chlorite, apatite and sphene. Texture schistose with gneissic banding weak: segregations of quartz up to 1 mm long occur.

2236

East end of tunnel on track in Nassfeldertal, 1 km west of Heilstollen. Hololeucocratic, granosyenite-gneiss showing evidence of crushing. Albite (An_8) and microcline in 1 mm bent and shattered grains set in albite-microcline-quartz groundmass of 0.2 mm. Mortar texture; weak schistosity due to traces of muscovite and biotite; no gneissic banding. Accessory epidote, sphene, apatite and calcite.

2245

Lowest cliff by path 500 m at 240° from church in Bockstein; a leucocratic "granite-gneiss" lying below augen gneisses of type 2093. Partly microclinised orthoclase, slightly perthitic, in rare 4 mm crystals, and albite up to 2 mm set in groundmass of microcline, albite and quartz, O.5—1 mm. The larger crystals are beginning to break up into a granular aggregate and do not form augen. Biotite and muscovite commoner than epidote; accessory sphene, apatite and chlorite. Texture resembles granitic rather than metamorphic; schistosity weak and gneissic banding absent. Although possessing a weathered crust in the field all minerals fresh in thin section.

2251

Path 350 m west of tunnel in Nassfeldertal (see 2236). Leucocratic biotite-epidote granite-gneiss from granosyenite-gneiss group. Euhedral microcline crystals, non-perthitic, but enclosing 1 mm albite crystals; form about 25% of rock. Remainder of eyes of 0.5 mm quartz crystals up to 4 mm long, lying between aggregates of 0.05 mm microcline, albite and quartz. Biotite (up to 2 mm) with equal quantities of epidote defines a weak foliation. Accessory apatite, sphene, calcite, iron oxide and chlorite.

2263

In stream section at 1670 m, Moderegg Graben, Gross Arl Tal. Gneissose granosyenite-gneiss about 5 m from contact with Schieferhülle. No thin section available.

2274

500 m southwest of summit of Lisgelespitz. Non-porphyritic leucocratic biotite-muscovite gneiss. Weakly perthitic K-feldspar up to 4 mm in broken crystals, but mostly in granular aggregate 0.5—1 mm with less common quartz and albite. Twinning rare in feldspars. Biotite

and muscovite define a weak schistosity. Thin foliae of quartz and feldspar are of finer grain (0.2 mm) than the rest. Accessory epidote, sphene, iron oxide and apatite.

2279

Hohenweg, 300 m northeast of Mindener Hütte. Coarse leucocratic augen-gneiss with 1.5 cm euhedral microclinised orthoclase, Carlsbad-twinned and weakly perthitic, containing euhedral albite crystals up to 1 mm. Quartz, albite and microcline in 0.1 mm groundmass, with rare eyes of quartz (0.5 mm) up to 1 cm long. Biotite and muscovite common in thin foliae and a few randomly orientated crystals (relative age not clear). Accessory epidote, chlorite, sphene and apatite.

2303

At foot of cliffs southwest of Mallnitz. Massive biotite-granite of granosyenite-gneiss type. 70% orthoclase microperthite (slightly microclinised) up to 1 cm, euhedral, with Carlsbad twins. Primary oligoclase (about An^{30}) 10%. Quartz, secondary albite and K-feldspar form fine-grained aggregate between primary orthoclase crystals. Aggregates of biotite and iron-rich epidote appear to be pseudomorphs after hornblende. Accessory sphene, apatite, iron oxide and calcite. Texture igneous (granitic), foliation very weak.

In general in the Central Gneisses, the augen form 10—20% of the rock, and consist of weakly perthitic K-feldspars with optical properties indicating partially microclinised orthoclase. They are seen to be in all stages of break-up, recrystallising as microcline, usually untwinned, and albite. Primary albite may be "porphyritic" but is usually of smaller grain-size than the K-feldspars. This albite commonly contains small euhedral crystals of iron-rich epidote, indicative of a formerly higher anorthite content; the epidote is usually accompanied by a small quantity of muscovite. Primary iron-rich epidote is rare, but both muscovite and biotite are present. The only sign of hydrothermal alteration is rare chloritisation of biotite: no kaolinisation or sericisation of the feldspars has been found, while tourmaline, topaz and other late-stage minerals are absent. Iron oxides and zircon are rare, but sphene is a prominent accessory. Reactions and replacements are confined to exsolution phenomena in the feldspars, with a rare development of myrmekite.

The granosyenite-gneisses are all richer in K-feldspar and poorer in quartz than the granite-gneisses; the K-feldspar is usually highly perthitic and is Carlsbad-twinned. The characteristic biotite-epidote aggregates are found in nearly all specimens. All stages between massive rocks of igneous character to well-banded gneisses may be found in this group: in thin section this change is marked by a progressive replacement of the igneous microperthites by granular aggregates of microcline and albite. Igneous textures and Carlsbad twins, indicative of magmatic crystallisation, are much better preserved in the granosyenite-gneisses than in the rest of the complex.

Die Ötztaler Schubmasse und ihre Umgebung

Von Oskar Schmidegg

(mit 3 Tafeln)

Die folgenden Ausführungen beruhen auf Beobachtungen, die ich bei Kartierungen und Einzelbegehungen im Laufe der Zeit seit meiner geologischen Aufnahme des Blattes Sölden — St. Leonhard machen konnte, so besonders im Gebiete des unteren Silltales, im Stubai, im unteren Pitztal und im Kaunertal, wo ich Gelegenheit hatte, für den Bau von Wasserkraftwerken geologische Aufnahmen durchzuführen.

Auch auf manche unveröffentlichte Ergebnisse von Begehungen auf der Südseite der Ötztaler Alpen im Vintschgau wird zurückgegriffen, deren weitere Ausarbeitung seinerzeit wegen der Kriegsereignisse zurückgestellt werden mußte. Das Material ist dann größtenteils einem Bombenangriff zum Opfer gefallen.

Über die Umgrenzung der Ötztaler Masse hat W. Hammer 1933 eine Arbeit veröffentlicht, die großenteils auf eigene Erfahrung beruhte und in der das damals Bekannte zusammengefaßt wurde. Manches davon wird hier wiederholt, das in neueren Synthesen noch zu wenig Beachtung gefunden hat.