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New Data on the Evolutionary History of the Ivrea Zone (Northern Italy)

with 6 Figures, 7 Tables, 1 Appendix
by

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Abstract

This paper intends to determine the metamorphic evolution, especially the cooling- uplift-history of the Ivrea zone, in a cross-section through the lower continental crust. In Val Strona di Postua 6 samples of a charnockite (qtz-feldspars-gar-bio-opx) with a granodioritic to tonalitic bulk chemistry were analysed with the Rb-Sr method, 4 of them defining an isochron of 274 ± 17 Ma with an Sr initial value of 0.71044 ± 0.00013. This 274 Ma isochron represents the Hercynian metamorphic peak. The subsequent cooling to a temperature below 300° C must be connected with the Early Mesozoic rifting in this region. The cooling curve for the Val Strona di Postua and the Val Sesia area is reconstructed by means of Rb-Sr and K-Ar age determinations on charnockite, diorite and pegmatite mica samples. 300° C in this region were reached about 210 Ma ago, whereas in Val Cannobina 350° C were reached about 180 Ma ago. The tilting of the Ivrea zone must have taken place after the cooling down of the whole block below the closure temperature of muscovite and biotite (K-Ar). The age-data of this report support the assumption that through differential uplift unequal crustal levels were brought up to the present surface, i.e. along strike there are different crustal levels on the same altitude caused by differential uplift. Perpendicular to the strike there are different crustal levels on the same altitude caused by tilting.

Equal apatite FT age of around 13 Ma north and south of the Insubric line indicates the same uplift rate in the Central and Southern Alps close to the Insubric line, at least since the Middle Miocene.

Zusammenfassung

Die Ivrea-Zone stellt ein einzigartiges Profil durch die untere Kruste bis zum oberen Mantel dar. Mit der vorliegenden Arbeit soll versucht werden die metamorphe Entwicklung, besonders die Abkühlungs-Hebungs-Geschichte genauer zu rekonstruieren. Im Val Strona di Postua, einem Seitental des Val Sesia, wurden 6 Charnockit-Proben (Qz-Fsp-Granat-Bio-Opx) mit granodioritischer bis tonalitischer Zusammensetzung eingehend untersucht. Vier dieser Proben definieren eine Rb-Sr Isochrone von 274 ± 17 Ma mit einem Sr Initialwert von 0.71044 ± 0.00013. Diese Isochrone wiederspiegelt den herzynischen Metamorphose-Höhepunkt der Ivrea-Zone. Die anschliessende Abkühlung auf Temperaturen unter 300° C hängt mit der allgemeinen Krustenausdünnung während des Mesozoikums im Südalpin zusammen. Die Abkühlgeschichte im Bereich Val Sesia/Val Strona di Postua wurde aufgrund von Rb-Sr und K-Ar Altersbestimmungen an Glimmern von Charnockit-, Pegmatit- und Dioritproben rekonstruiert. Demnach wurde hier die 300° C Grenze vor etwa 210 Ma unterschritten. Im Val Cannobina, einem Zuflusstal zum Lago Maggiore, wurde hingegen die 350° C Grenze erst vor ca. 180 Ma erreicht. Die Kippung der Ivrea-Zone in ihre heutige subvertikale Lage muss nach der Schliessung des K-Ar Systems für Muskowit und Biotit stattgefunden haben. Die Verteilung der Altersdaten legt die Vermutung nahe, dass in der Ivrea-Zone differentielle Hebung stattgefunden hat: Parallel zum Streichen der Ivrea-Zone sind deshalb heute als deren Ergebnis unterschiedlich tiefe Krustenniveaus aufgeschlossen. Senkrecht zum Streichen liegen, bedingt durch die Kippung, ebenfalls verschieden tiefe Niveaus auf derselben Höhe.

Gleiche Apatit Spaltspur-Alter von ungefähr 13 Ma nördlich und südlich der Insubrischen Linie zeigen an, dass die Zentral- und die Südalpen seit dem Mittelmiozän ungefähr die gleiche Hebungsrate aufweisen.

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1. Introduction

The Ivrea zone in northern Italy represents a cross-section through the lower continental crust and, possibly, the upper mantle, and its evolutionary history (P-T conditions as well as the ages of magmatic and metamorphic evolution) is still a source of controversy. Evidence has been found recently, which indicates a widespread Alpine influence in the Ivrea zone such as large scale folding (S. SCHMID et al., 1987; S. SCHMID, 1988). The Alpine influence may have been underestimated for a long time by geologists and petrologists primarily concerned with magmatic or high grade metamorphic processes.

It has been known for a long time that the rocks of the Ivrea zone are of pre-Alpine age (e.g. HUTTENLOCHER, 1942). This assumption was confirmed by the first radiometric studies carried out by JÄGER & FAUL (1960) and Jäger et al. (1967). Time-temperature diagrams were later drawn up by HUNZIKER (1974) and by HUNZIKER & ZINGG (1980). Nevertheless it is still debated whether the main metamorphic event in the Ivrea zone was Hercynian or Caledonian (see also ZINGG, 1983).

We have studied in detail two different areas of the Ivrea zone which lie about 50 km apart and we attempt here to draw one picture out of the results obtained. The aim of this paper is to *describe more precisely the cooling and uplift of the Ivrea zone,* and to this end isotopic measurements on 6 whole-rock (Rb-Sr) and 33 mica samples (22 K-Ar and 11 Rb-Sr) and 6 fission track (FT) analyses on apatite and one on a zircon sample were undertaken.

2. Geological Setting

2.1 The Ivrea zone

The Ivrea zone belongs to the westernmost part of the Southern Alps and extends over about 160 km from Ivrea in northern Italy to Locarno in southern Switzerland. The northwestern edge of the Ivrea zone is defined by the Insubric line, which separates the Tertiary metamorphic rocks of the Central Alps from the pre-Alpine metamorphic rocks of the Southern Alps. To the east and to the south of the Ivrea zone, occur rocks of the Serie dei laghi (or «Strona-Ceneri zone») and Late Palaeozoic volcanites and granites. The boundary between the Ivrea zone and the Serie dei Laghi is given by the Pogallo line, which was interpreted by HANDY (1987) as oblique-extensional fault due to E-W attenuation of the upper crust in the Late Triassic and Early Jurassic.

The Ivrea zone consists mainly of three different rock units:

(1) large ultramafic bodies of mantle origin (e.g. Rivalenti et al., 1975)

(2) the Main Basic Formation «Basischer Hauptzug» with metamorphosed norites, gabbros and, in the Sesia Valley, diorites s.l. (BERTOLANI & GARUTI, 1970; BIGIOGGERO et al., 1979)

(3) the Kinzigitic series, consisting of amphibolite to granulite facies paragneisses with local anatexis, and less abundant marbles and amphibolites (ZINGG, 1983).

According to R. SCHMID (1979) the paragneisses of the Kinzigitic series must be considered as restites. He estimated that the paragneisses of the Ivrea zone lost up to 60% of their volume by «degranitization» during metamorphism.

In general, the metamorphic grade increases from amphibolite facies (in the NW Serie dei Laghi and SE Ivrea zone) to granulite facies in the NW part of the Ivrea zone. P-T conditions for the climax of metamorphism in the granulite facies part of the Ivrea

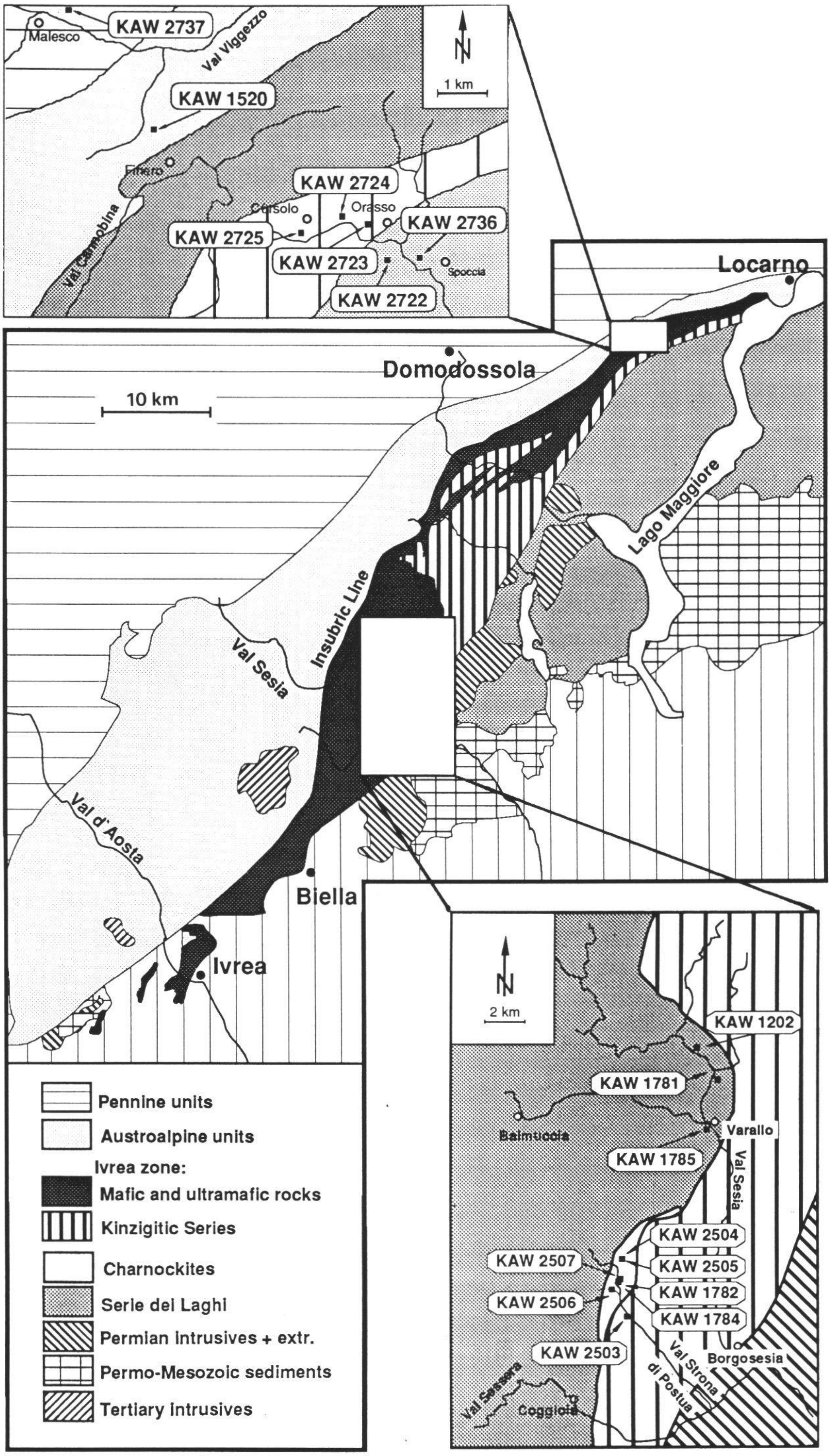

Figure 1: Geological sketch map of the Ivrea zone showing the sample localities

zone have been calculated by several authors. R. SCHMID & WOOD (1976) proposed 9 - 11 kbars and 700 - 800° C for the Val d'Ossola cross section and SILLS (1984) gives 8 ± 0.5 kbars and 750 - 800° C for the Val Sesia cross section. R. SCHMID et al. (1988) calculated 8.3 ± 0.5 kbars, 940 ± 60° C and a(H_2O) < 0.4 for the granulite facies metapelitic paragneisses of the Val d'Ossola cross section. ZINGG (1978) as well as SILLS (1984) emphasize a considerable variation of pressure estimates along the strike of the Ivrea zone.

The age of metamorphism in the Ivrea zone is the subject of numerous papers. HUNZIKER & ZINGG (1980) proposed a Caledonian metamorphic peak based on a whole rock Rb-Sr isochron of 478 ± 20 Ma on paragneiss samples from the Kinzigitic series. However, in view of the fact that the initial $^{87}Sr/^{86}Sr$ of 0.7086 ± 0.0008 conforms to the sea-water $^{87}Sr/^{86}Sr$ value 480 Ma ago (BURKE et al., 1982; FAURE, 1986), another possible interpretation is, that the age corresponds to the age of sedimentation of the Kinzigitic series.

PIN (1986) reported zircon U-Pb data on 6 fractions of a diorite sample from Val Sesia. The fractions are nearly concordant with an upper intercept of 285 +7/-5 Ma, which was interpreted as the intrusion age of the Main Basic Formation. Similar ages were found in the paragneisses from the Val d'Ossola by KÖPPEL (1974) and KÖPPEL & GRÜNENFELDER (1979). In this valley concordant monazites yieldel U-Pb ages of 275 ± 5 Ma. VOSHAGE et al. (1988) reported Nd and Sr isotopic data, which give an age of around 270 Ma for websteritic dikes and gabbroic pods from the Balmuccia peridotite. BEN OTHMAN et al. (1984) and VOSHAGE et al. (1987) reported several Sm-Nd mineral isochrons from the Main Basic Formation and from the Kinzigitic series ranging from 230 to 270 Ma. It is suggested that these are related to the same tectonic event that produced the Baveno-Mt'Orfano granites at 278 ± 3 Ma (HUNZIKER & ZINGG, 1980) and the Lugano volcanic rocks at 262 ± 1 Ma (STILLE & BULETTI, 1987). STILLE & BULETTI suggest that this tectonic event was an Andean-type subduction environment synchronous with the final phase of convergence of Gondwana and Laurasia, i.e. the final closure of the Proto-Tethys.

Mica ages on Ivrea zone rocks have been published by JÄGER et al. (1967), HUNZIKER (1974) and BORIANI et al. (1987); see also ZINGG (1983). Biotite ages (K-Ar and Rb-Sr)lie between 162 and 213 Ma. K-Ar muscovite ages range from 220 to 230 and Rb-Sr muscovite ages range from about 220 to 250 Ma.

STÄHLE et al. (1986) found significantly younger $^{40}Ar/^{39}Ar$ ages in a retrograde shear zone from the peridotite complex of Finero, about 1.5 km south-east of the Insubric line: 57 ± 3 Ma for a margarite and 26 ± 3 Ma for a muscovite. Both ages are interpreted as formation ages.

Few fission track-ages have been reported up to now. WAGNER & REIMER (1972) give apatite ages of the Southern Alps between 14.2 Ma and 9.2 Ma (± 10%). HURFORD (1986) reports two FT ages from Porto Ronco (lakeside of Lago Maggiore, Switzerland): 48.2 ± 3.7 Ma for zircon and 15.0 ± 2.2 Ma for apatite.

2.2 Val Strona di Postua and Val Sesia

Val Strona di Postua lies in the SW part of the Ivrea zone, a few km west of the southern Val Sesia (Fig. 1). About half of Val Strona di Postua consists of rocks from the Main Basic Formation. The other half of the valley is composed of rocks from the Kinzigitic series: anatectic metapelitic paragneisses at granulite facies, pyroxene amphibolites and some marbles.

The muscovite-K-feldspar isograd of ZINGG (1978) runs south of the area investigated, i.e. all the paragneisses lie in the K-feldspar stability field (BÜRGI, 1987). The Kinzigitic series is cut by posttectonic pegmatites.

At the contact (running SSW - NNE) between the Main Basic Formation and the Kinzigitic series, there is a migmatite with a raft structure (schollen structure). The leucosome of this migmatite intrudes and is thus younger than the Main Basic Formation. This leucosome is largely a light-coloured charnockite with a magmatic fabric and with white K-feldspar porphyroblasts. Locally, the leucosome of the migmatite is a darker charnockite with a metamorphic fabric and devoid of K-feldspar megacrysts. The paragenesis for both types of charnockites is qtz - feldspar (antiperthite, mesoperthite, perthite) - gar - bio - opx (hypersthene) (BÜRGI, 1987). In many cases the biotites have been hydrothermally altered to prehnite parallel to (001). The «schollen» of the migmatite are relics of the Kinzigitic series.

ZINGG (1978) first described these rocks in Val Strona di Postua and he grouped the charnockites with the intermediate rim of the Main Basic Formation. He considered the possibility that the charnockites might be a differentiation product from the diorites s.l., which are well developed in Val Sesia. Geochemical considerations preclude this since, for example, the charnockites are significantly lower in K_2O (2.7%, average of 6; BÜRGI, 1987) than the diorites s.l. (4.1%, average of 13; BIGIOGGERO et al., (1979). Further, the light charnockite shows only a very weak metamorphic overprint and intruded during or after plastic deformation related to peak metamorphism. This deformation formed the main foliation in the surrounding paragneisses (CAPREDI & RIVALENTI, 1973).

Six whole rock samples of the charnockites (4 from light and 2 from the dark charnockites) were analysed with Rb-Sr. The biotites from these samples were all investigated with both Rb-Sr and K-Ar methods. From a discordant two-mica pegmatite which cuts the Kinzigitic series biotite and muscovite (both about 25 cm in diameter) were dated with Rb-Sr and K-Ar.

Three biotite samples out of the diorites s.l. which form the roof of the intrusion of the Main Basic Formation in Val Sesia (RIVALENTI et al., 1975; BIGIOGGERO et al., 1979; BÜRGI, 1987) had been compared with the results from the Val Strona di Postua mica samples.

2.3 The upper Val Cannobina

The second area investigated is situated in the upper Val Cannobina (Prov. Novara) in the vicinity of Cùrsolo (Fig. 1). Its northern edge is formed by the peridotite complex of Finero, the southern one by the transition between the Ivrea zone and the Serie dei Laghi. The entire upper valley has never been studied in detail, although many papers concerning the peridotite complex of Finero have been published (KRUHL, 1979; STECK & TIÈCHE 1976; LENSCH, 1971; VOGT, 1962). Petrological descriptions of the rocks investigated can be found in WALTER (1950) and PAPAGEORGAKIS (1961).

The northern half of the region investigated comprises the Main Basic Formation, consisting of different types of amphibolites and metamorphosed basic to ultrabasic rocks. The southern part is built up by the Kinzigitic series and consists of kinzigites s.s. and muscovite-biotite-sillimanite-gneisses with intercalations of marbles, calc-silicate rocks, amphibolites and pegmatites. The metamorphic grade of the rocks varies from upper amphibolite facies in the south to granulite facies in the north.

KAW No	Rocktype	Locality	Mineralogy	Description
Val Strona di Postua Samples				
1782	light coloured Charnockite	Alpe Archivoit 659.200/066.050	qz 30, plag 25, Kfsp 29, bio 7, gar 9, opx < 1	magmatic fabric, myrmekites, perthites, antiperthites. Bio partly altered to prehnite
1784	dark Charnockite	Alpe Archivoit 659.200/066.050	qz 9, plag 52, Kfsp 7, opx 18, bio 14, gar <1	granoblastic fabric, antiperthitic plagioclase. Bio partly altered to prehnite
2504	light coloured Charnockite	Alpe Uccei 659.830/067.720	qz 35, plag 39, Kfsp 12, opx 2, bio 7, gar 5	magmatic fabric, myrmekites, perthites, antiperthites. Bio partly altered to prehnite
2505	dark Charnockite	Alpe Lote 659.990/067.660	qz 15, plag 50, Kfsp 2, opx 15, bio 18, no gar	granoblastic fabric, antiperthitic plag, myrmekites. Bio partly altered to prehnite
2506	light coloured Charnockite	Val Canale 659.060/065.620	qz 29, plag 39, Kfsp 14, opx 1, bio 13, gar 4	magmatic fabric, myrmekites, perthites, antiperthites. Bio partly altered to prehnite
2507	light coloured Charnockite	Alpe Archivoit 659.190/066.230	qz 32, plag 31, Kfsp 16, opx 6, bio 12, gar 3	magmatic fabric, perthites, microperthites, myrmekites. Bio partly altered to prehnite
2503	Pegmatite	Val Strona 659.550/064.660	plag 50, qz 30, musc 10, bio 10, no primary Kfsp	very coarse grained, slightly cataclastic. Micas 25 cm in diameter, kinked. Country rock: granulite facies paragneisses of the Kinzigitic Series
Val Sesia Samples				
1202	Monzonite	Val Mastallone 663.000/077.300	plag 45, Kfsp 12, bio 22, hbl 2, opx 12, cpx 4	magmatic fabric; bio -> opx + plag; zircon 1-2% (!)
1781	Diorite s.s.	Val Mastallone 663.750/076.200	qz 4, plag 62, bio 12, hbl 17, ilmenite 2	granoblastic fabric, mafic minerals corroded to chlorite, white mica, clinozoisite and calcite (3 %)
1785	Monzodiorite	Crevola Varallo 663.300/073.700	qz 2, plag 58, Kfsp 15, bio 20, hbl 5, opaques <1	mafic minerals corroded, see Voshage et al., (1987)
Val Cannobina Samples				
1520	Reinhardt-Porphyr	Piano di Sale 684.300/107.400	bio 5, musc 15, Kfsp 30 qz 30, fsp 20	strongly mylonitic with qz- and fsp-clasts. Country rock: biotite gneisses of the Sesia zone
2722	Pegmatite	Ponte Gurro 688.390/105.060	musc 5-10, qz 40 plag 40-45, ap 1	fine-grained, polygonal texture with plag-clasts, musc evenly distributed. Country rock: biotite gneisses of the Serie dei Laghi
2723	Pegmatite	Orasso 688.430/105.530	musc 5, bio 5, qz 40 Kfsp 20, plag 30	medium-grained, slightly mylonitic, bio partly chloritized. Country rock: paragneisses Ivrea zone
2724	Pegmatite	Airetta 687.980/105.720	bio 5, musc 5, qz 30 Kfsp 60	medium-grainded, fsp sericitized, bio chloritized. Country rock: paragneisses Ivrea zone
2725	Pegmatite	Airetta 686.940/105.435	musc 5, bio 5, qz 45 Kfsp 40, sil 5	medium to coarse-grained, slightly cataclastic, intense intergrowth musc-sil. Country rock: paragneisses Ivrea zone
2736	Augengneis Serie dei Laghi	Spoccia 689.550/105.050	bio 5, musc 10, qz 65 plag 20	medium-grained, myrmekitic fsp, bio very dark
2737	Augengneis Monte Rosa nappe	Malesco-Centovalli 682.850/109.300	bio 15, musc 10, qz 20 plag 25, Kfsp 30	coarse grained, myrmekitic fsp, in parts slightly mylonitic

Table 1: Sample descriptions and locations. The marked co-ordinates refer to the Swiss kilometer grid from the maps of the Swiss topographic survey. The given modes are estimated.

Four concordant pegmatites and one augengneiss were investigated with the K-Ar and fission track method. The samples were collected from the paragneisses in a cross section between the Main Basic Formation and the northernmost Serie dei Laghi (Fig. 1). The samples KAW 1520 and KAW 2737 were collected from the Alpine metamorphic units north of the Insubric line (Fig. 1). These two samples were only analyzed with the FT method.

3. Analytical Techniques

All rock samples treated for this work were 15 to 30 kg. All sample preparation, mineral separation, isotopic and FT measurements were carried out at the Dept. of Isotope Geol., Univ. of Berne using conventional techniques. Only one fraction of each of the Val Sesia and Val Strona di Postua mica samples was analysed (the biggest grain size obtained) whereas two grain size fractions were analysed in the Val Cannobina samples, whenever possible.

Rb and Sr contents were determined according to the isotope dilution method described by JÄGER (1979). Rb and Sr were measured on an AVCO solid source mass spectrometer with a triple filament ion source, running under DEC PDP-11 automation. The error limit in the $^{87}Rb/^{86}Sr$ is about $\pm$ 1% (1 σ) and for the $^{87}Sr/^{86}Sr$ about $\pm$ 0.01% (1σ). The NBS 987 standard $^{87}Sr/^{86}Sr$ ratio was measured as 0.710257 $\pm$ 0.000069 (1σ).

Ar measurements were carried out on a VG MM 1200, which is also run through a DEC PDP-11 computer. The Ar extraction line is described by FLISCH (1982, 1986). As reported by FLISCH (1986), the blank is 3 to $7 \cdot 10^{-9}$ cm^3 STP ^{40}Ar and measured $^{40}Ar/^{36}Ar_{(air)}$ is 303.3 $\pm$ 0.5 (1σ) for amounts of $< 2.1 \cdot 10^{-6}$ cm^3 STP ^{40}Ar.

The error limit of the Ar-measurements is about $\pm$ 1% (1 σ); the measurements and results of the Ar-determinations were periodically checked using the standards B4B, B4M, GLO and LP-6. K-measurements were carried out by flame-photometry, the reproducibility for micas lying within the 1% limit.

For all Rb-Sr and K-Ar age measurements and age calculations the constants recommended by the IUGS were used (STEIGER & JÄGER, 1977).

The FT ages were determined using the zeta-calibration method described by HURFORD & GREEN (1983).

Major and trace element XRF analyses from the charnockites have been obtained on a fully automated sequential Philips spectrometer. Major elements were measured on Li-tetraborate glass disks, trace elements were measured using powder tablets.

4. Results

Table 1 shows the locality and the petrographic description of the samples (see also Fig. 1).

4.1 The charnockite whole-rock analyses

The geochemical composition of the whole-rock samples from the charnockites is given in Appendix 1 and the results of the isotopic measurements of the charnockites in Table 2. Light charnockites are granodioritic in composition and the darker charnockites are qtz-dioritic to tonalitic in composition (Fig. 2).

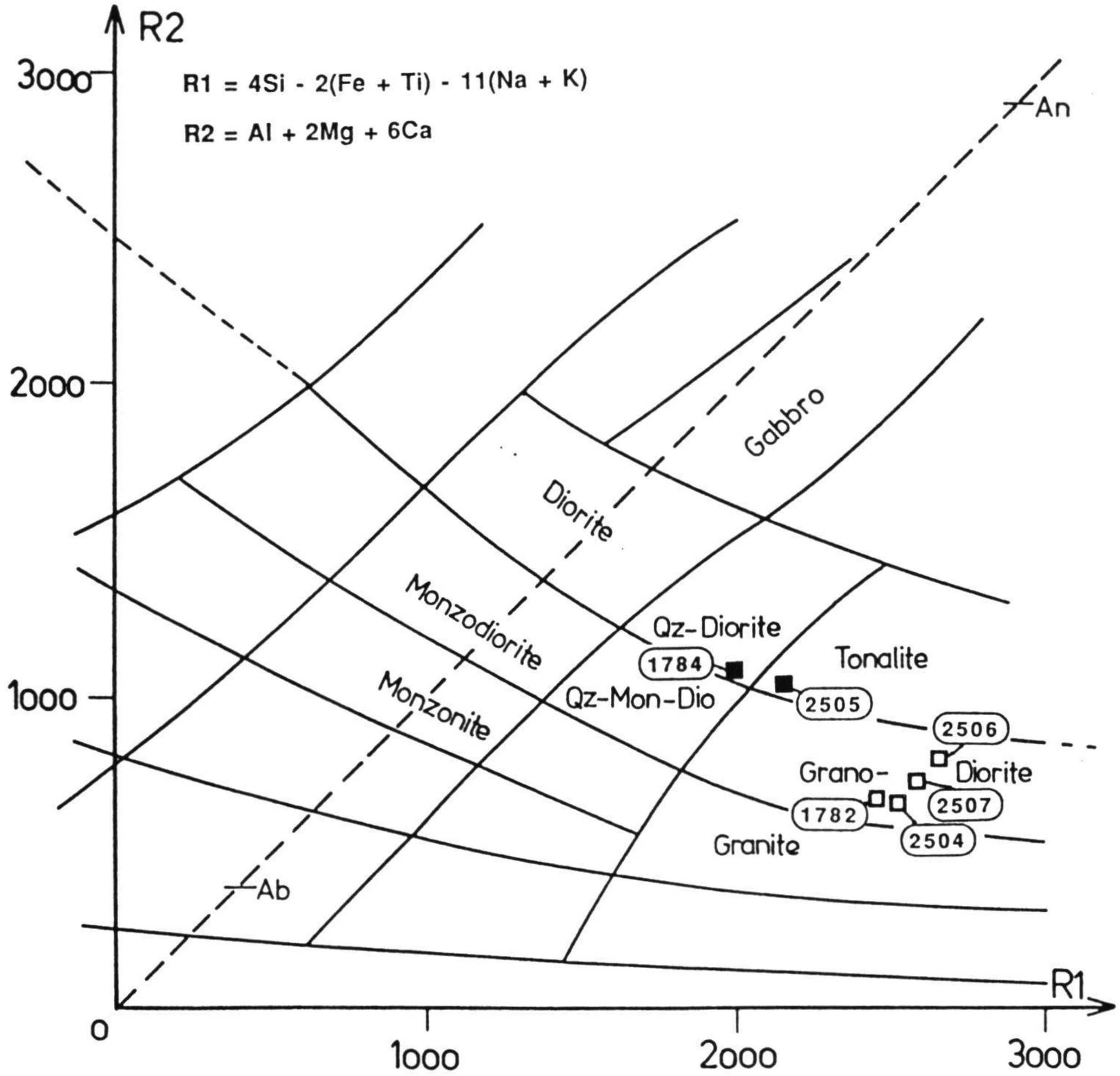

Figure 2: Classification of the charnockite whole-rock samples from Val Strona di Postua in the R1-R2 diagram after DE LA ROCHE et al. (1980), modified by STRECKEISEN (1981). *Open squares:* light coloured charnockites, *filled squadres:* dark charnockites.

A clear difference between these two rock types can also be found in their isotopic composition. The light charnockites define a straight line with a slope corresponding to an age of 274 ± 17 Ma (2 σ). The initial $^{87}Sr/^{86}Sr$ ratio of these samples is 0.71044 ± 13 (2 σ), calculated after YORK (1969, part I). The dark charnockite samples are clearly off this line, having considerably lower $^{87}Sr/^{86}Sr$ values (see Fig. 3). The slope through these two points in the $^{87}Sr/^{86}Sr$ vs $^{87}Rb/^{86}Sr$ diagram corresponds to a «date» of 214 Ma, with an Sr initial value of 0.7089.

4.2 The micas from Val Strona di Postua and Val Sesia

The results of the K-Ar measurements are listed in Table 3 and the results of the Rb-Sr measurements in Table 4.

The Rb-Sr as well as the K-Ar ages cover a considerable range and at first sight

KAW No.	Rb total ppm	Sr total ppm	87Sr/86Sr (±1 sigma)	87Rb/86Sr (±1 sigma)	Age in Ma (±1 sigma)	Sr initial (±1 sigma)
1782	78.76	413.66	0.71270 0.00005	0.5511 0.0055		
2504	91.27	320.63	0.71361 0.00009	0.8241 0.0082	273.6 16.6	0.71044 0.00013
2506	44.12	439.75	0.71158 0.00008	0.2904 0.0029		
2507	69.05	519.22	0.71188 0.00007	0.3849 0.0038		
1784	48.50	468.24	0.71071 0.00008	0.2997 0.0030		0.7098
2505	59.38	398.99	0.71111 0.00006	0.4307 0.0043		

Table 2: Results of the Rb-Sr measurements on 25 to 30 kg whole-rock samples for the charnockites from Val Strona di Postua.

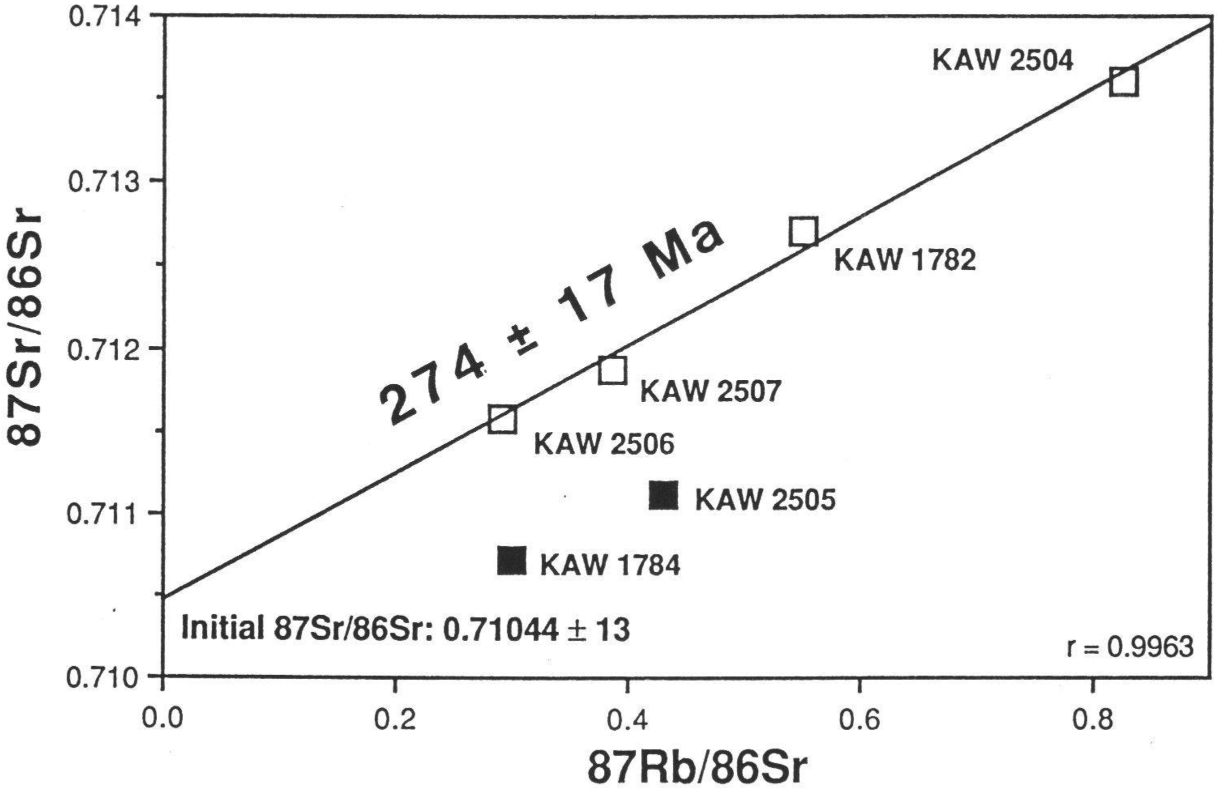

Figure 3: Rb-Sr isochron diagram for the charnockite whole-rock samples from Val Strona di Postua. *Open squares:* light coloured charnockites, *filled squares:* dark charnockites.
The size of the squares corresponds to the mean analytical error.

provide a rather confusing picture. Biotites should indicate the same age for both Rb-Sr and K-Ar systems, if the system remained closed in terms of the radiometric clocks (PURDY & JÄGER, 1976). Only the data of the biotite from the pegmatite (KAW 2503) in Val Strona di Postua gives concordant age results of about 211 Ma.

The biotites from the charnockites yield systematically higher Rb-Sr ages than K-Ar ages (see Table 5).

When plotted in the diagram $^{40}Ar/^{36}Ar$ vs $^{40}K/^{36}Ar$ (Fig. 4) the three biotite samples from the diorites s.l. from Val Sesia show a well defined straight line. The slope of this line corresponds to an age of 211 $\pm$ 3 Ma (1 σ), the intercept on the y-axis has a value of -1530.3 $\pm$ 19.0 (1 σ). The diagram $^{40}Ar/^{36}Ar$ vs $1/^{36}Ar$ shows approximately the same intercept, which has an exact value of -1584.2 $\pm$ 167.0 (1 σ), see Fig. 5.

KAW No.	fraction in mesh	% K (±1 sigma)	40 Ar rad in mol/g (±1 sigma)	% 40 Ar rad	40Ar/36Ar (±1 sigma)	40K/36Ar (±1 sigma)	Age in Ma (±1 sigma)
Diorites s.l.:							
1202 Bio	35-60	7.55	2.59285E-09	97.92	14185.2	1.2063E+06	188.0
		0.08	1.99966E-11		117.4	1.1552E+04	2.2
1781 Bio	35-60	7.16	2.55333E-09	98.71	22663.0	1.8722E+06	194.7
		0.07	2.19864E-11		180.9	1.9127E+04	2.4
1785 Bio	40-60	7.54	2.75946E-09	99.02	30218.5	2.4405E+06	199.6
		0.08	1.66594E-11		176.3	2.2886E+04	2.1
Charnockites:							
1782 Bio	35-100	7.43	2.51318E-09	98.88	26391.7	2.3026E+06	185.2
		0.07	1.58474E-11		159.9	2.1962E+04	2.0
1784 Bio	60-80	7.96	2.74295E-09	98.92	27377.2	2.3458E+06	188.5
		0.08	2.02018E-11		190.4	2.4131E+04	2.2
2504 Bio	60-100	7.48	2.56315E-09	99.26	40095.5	3.4667E+06	187.5
		0.07	1.74044E-11		260.1	3.3066E+04	2.1
2505 Bio	35-60	7.71	2.59215E-09	98.53	20075.1	1.7537E+06	184.4
		0.07	2.2214E-11		161.6	1.6577E+04	2.2
2506 Bio	60-100	7.31	2.53281E-09	98.69	22549.4	1.9172E+06	189.5
		0.07	1.78952E-11		151.1	1.8742E+04	2.1
2507 Bio	60-100	7.71	2.68406E-09	99.11	33162.1	2.8179E+06	190.3
		0.08	1.8038E-11		212.6	2.6095E+04	2.0
Pegmatites:							
2503 Musc	single	8.56	3.36306E-09	96.57	8622.2	6.3260E+05	213.4
	crystal¶	0.09	2.21403E-11		54.4	6.2023E+03	2..3
2503 Bio	single	7.66	2.98155E-09	98.65	21813.5	1.6501E+06	211.5
	crystal¶	0.08	1.73549E-11		127.7	1.7457E+04	2.4

Table 3: Results of K-Ar measurements on micas from Val Sesia and Val Strona di Postua. ¶ These single crystals were crushed to a grain size of 40-80 mesh, which were then taken for analyses.

KAW No.	fraction mesh	Rb total ppm	Sr total ppm	87Sr/86Sr (±1 sigma)	87Rb/86Sr (±1 sigma)	Age in Ma (±1 sigma)
Diorites s.l.:						
1202 Bio	35-60	125.28	10.48	0.80302 0.00004	34.907 0.349	189.7* 2.8
1781 Bio	35-60	164.73	9.24	0.85313 0.00006	52.309 0.523	194.2* 2.0
1785 Bio	40-60	289.08	6.11	1.09244 0.00003	142.098 1.421	189.5* 1.9
Charnockites:						
1782 Bio	35-100	496.38	7.64	1.26155 0.00004	198.056 1.981	195.4* 2.0
1784 Bio	60-80	388.92	9.98	1.04870 0.00007	116.531 1.165	204.5* 2.1
2504 Bio	60-100	599.59	6.58	1.50805 0.00008	284.331 2.843	197.1* 2.0
2505 Bio	35-60	333.54	10.69	0.95364 0.00012	92.452 0.925	185.4* 1.9
2506 Bio	60-100	394.29	9.88	1.04925 0.00015	119.369 1.194	199.4* 2.0
2507 Bio	60-100	419.91	9.83	1.06644 0.00006	127.887 1.279	195.6* 2.0
Pegmatites:						
2503 Musc	single crystal¶	1311.41	4.33	5.08331 0.00005	1251.350 12.514	245.0# 3.3
2503 Bio	single crystal¶	1787.45	4.13	6.66873 0.00009	1982.410 19.824	210.9# 2.6
2503 Plag	60-80	97.23	132.99	0.72229 0.00007	2.118 0.021	- -

Table 4: Results of Rb-Sr measurements on micas from Val Sesia and Val Strona di Postua. ¶ These single crystals were crushed to a grain size of 40-80 mesh, which were then taken for analyses. * These ages are calculated with the measured $^{87}Sr/^{86}Sr$ of the whole rock (see BÜRGI, 1987; VOSHAGE et al., 1987). # These ages are calculated with the $^{87}Sr/^{86}Sr$ value of the plagioclase KAW 2503, 60-80 mesh.

KAW No.	K-Ar age in Ma	Rb-Sr age in Ma total corrected	difference in Ma (Rb-Sr age)-(K-Ar age)
Diorites s.l.:			
1202 Bio	188.0 ± 2.2	189.7 ± 2.8	+1.7
1781 Bio	194.7 ± 2.4	194.2 ± 2.0	-0.5
1785 Bio	199.6 ± 2.1	189.5 ± 1.9	-9.9
Charnockites:			
1782 Bio	185.2 ± 2.0	195.4 ± 2.0	+10.2
1784 Bio	188.5 ± 2.2	204.5 ± 2.0	+16.0
2504 Bio	187.5 ± 2.1	197.1 ± 2.0	+9.6
2505 Bio	184.4 ± 2.2	185.4 ± 2.0	+1.0
2506 Bio	189.5 ± 2.1	199.4 ± 2.0	+9.9
2507 Bio	190.3 ± 2.0	195.6 ± 2.0	+5.3

Table 5: Comparison of Rb-Sr ages and K-Ar ages of the biotites from Val Sesia and Val Strona di Postua.

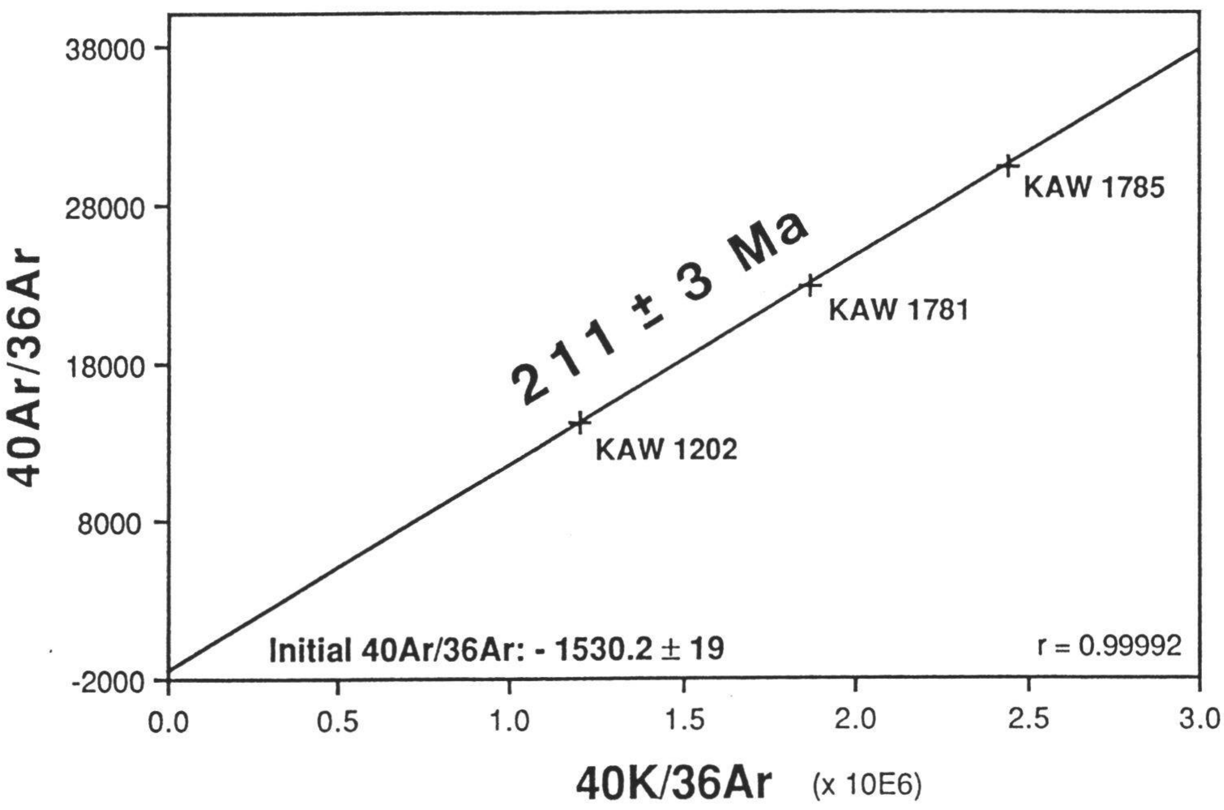

Figure 4: K-Ar isochron diagram for the biotites from the diorites s.l. in Val Sesia.

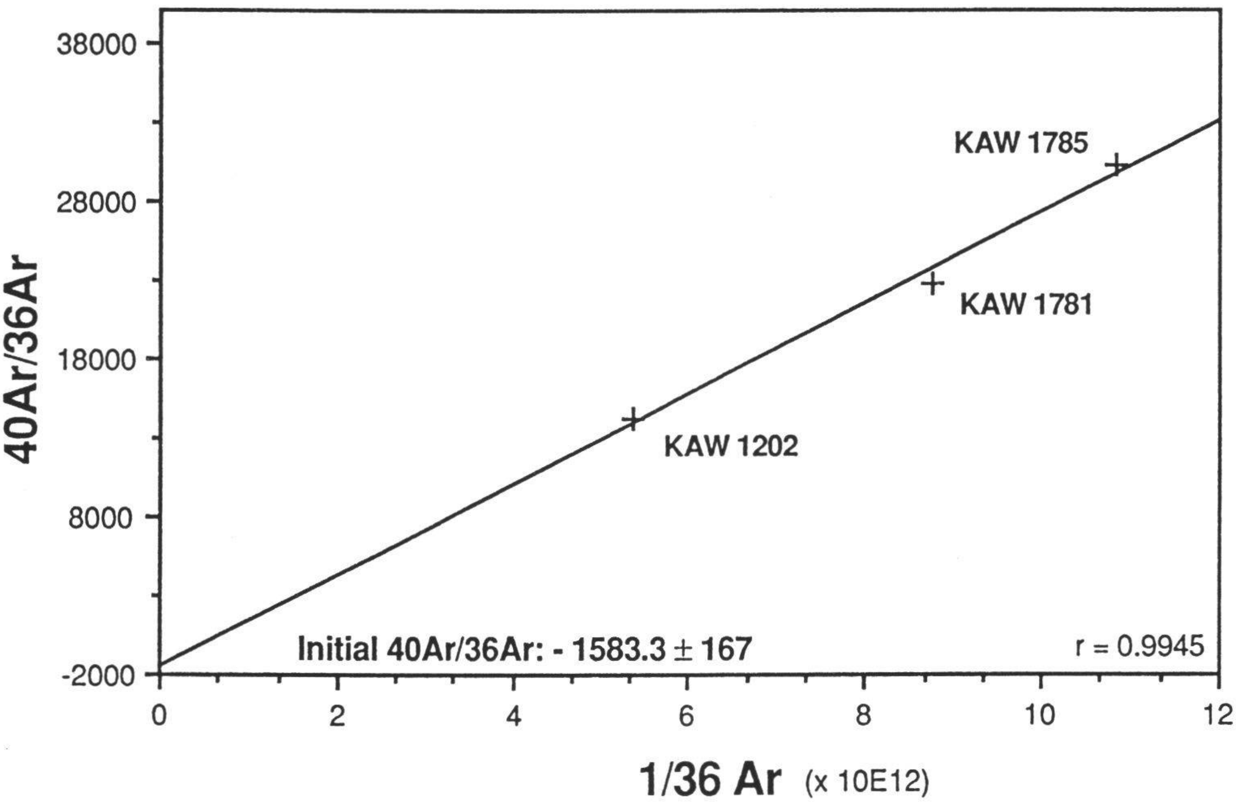

Figure 5: $^{40}Ar/^{36}Ar$ vs $^{1/36}Ar$ plot for the biotites from the diorites s.l. in Val Sesia.

4.3 The micas from the upper Val Cannobina

The results of the K-Ar measurements are listed in Table 6.

The 4 pegmatites of the southern Ivrea zone and northern Serie dei Laghi (KAW 2722, 2723, 2724, 2725) give K-Ar ages on muscovite between 182.4 ± 2 Ma and 171.2 ± 2 Ma (1 σ). The age of one muscovite (KAW 2725) which is intensely intergrown with sillimanite, is not significantly different from the > 99.9% pure muscovite samples, showing that sillimanite does not incorporate any argon. The biotites KAW 2722, 2723, 2724, 2725, 2736) show ages between 157 Ma and 121 Ma. Microscopically they all show different degrees of alteration, mainly chloritization, which evidently rejuvenated the K-Ar ages to variable degrees.

4.4 The FT ages

The results of the measurements are listed in Table 7.

The apatite FT ages (KAW 1520, 2722, 2723, 2725, 2736) are within the error limit the same and lie between 11.9 and 13.7 ± 1.2 Ma (1 σ). The sample from the Monte Rosa steep belt (KAW 2737) shows an age of 10.8 ± 0.8 Ma (1 σ). The apatite track lengths shows a mean value of 13.25 ± 1.4 μm (1 σ), indicating a rather slow cooling rate.

The only analyzed zircon sample (KAW 2736) gives an age of 63.6. ± 3.6 Ma (1 σ).

KAW No	fraction mesh	% K (±1 sigma)	40 Ar rad in mol/g (±1 sigma)	% 40 Ar rad	40Ar/36Ar (±1 sigma)	40K/36Ar (±1 sigma)	Age in Ma (±1 sigma)
2722 Musc	> 10	8.23 0.08	2.740E-09 1.704E-11	92.87	4142.1 25.0	344851 3423.03	182.4 2.0
2722 Musc	60 - 90	7.77 0.08	2.471E-09 1.481E-11	98.94	27845.7 159.2	2585920 26941.6	174.6 2.0
2723 Musc	> 35	8.89 0.09	2.768E-09 2.042E-11	96.43	8285.3 64.5	765761 8068.14	171.2 2.0
2723 Bio	> 35	6.37 0.06	1.452E-09 1.603E-11	92.24	3809.6 50.3	460237 4480.52	126.9 1.8
2723 Bio	60 - 90	4.38 0.04	9.468E-10 5.763E-12	95.84	7109.0 46.1	940756 8632.56	120.5 1.3
2724 Musc	> 10	8.21 0.08	2.596E-09 1.586E-11	98.62	21396.0 123.1	1991700 19741	173.7 1.9
2724 Bio	> 10	5.47 0.05	1.555E-09 1.244E-11	97.63	12493.8 94.9	1280700 11950.5	156.9 1.8
2724 Chlo	> 10	3.33 0.03	8.047E-10 4.519E-12	98.62	21360.2 125.5	2601910 23469.7	134.2 1.4
2725 Musc	60 - 90	3.96 0.04	1.260E-09 1.094E-11	97.08	10132.2 83.7	922628 9458.03	174.8 2.2
2725 Bio	60 -90	7.25 0.07	1.840E-09 1.264E-11	98.02	14890.2 96.0	1716630 16920.7	140.7 1.6
2736 Bio	60 - 90	7.73 0.08	2.024E-09 1.481E-11	97.96	14500.1 97.9	1618980 17221.9	145.0 1.8

Table 6: Results of K-Ar measurements on micas from the upper Val Cannobina.

KAW No.	Age in Ma	Track length in µm
1520	12.9 ± 1.0	13.49 ± 1.40
2722	12.5 ± 0.7	13.42 ± 1.26
2723	11.9 ± 0.6	13.34 ± 1.25
2725	12.7 ± 0.6	13.54 ± 1.30
2736	13.7 ± 1.2	12.46 ± 1.21
2737	10.8 ± 0.8	12.96 ± 12.55

Table 7:
Results of fission track measurements on apatites from the upper Val Cannobina and Val Vigezzo.

5. Discussion and Interpretation

5.1 The charnockite whole-rock samples

Several features of the charnockites correspond to those of S-type «granites» (PICHTER, 1983), such as

— high but narrow range of SiO_2,
— ilmenite, garnet and red biotite,
— white K-feldspar megacrysts,
— metasedimentary xenoliths,
— initial $^{87}Sr/^{86}Sr$ ratio of 0.71044.

It is thus possible that the charnockites represent a small part of the granitoid melt released from the paragneisses in the sense of R. SCHMID (1979). However, the charnockites are far from any minimum melt composition in the system Qz-Ab-Or-An-H_2O (WINKLER, 1979; JOHANNES, 1985) but formed under P-T conditions in the same range as were proposed by SILLS (1984) for the nearby paragneisses.

Another question which has not yet been answered satisfactorily is the source of the high CO_2 content. The latter is required to keep the orthopyroxenes stable in an acidic melt of a charnockite (WINKLER, 1979; GRANT, 1986).

The age of the charnockites:
With the exception of some 5% of the biotites which are altered to prehnite, the rock-forming minerals show no alteration. The prehnitization starts at a biotite-plagioclase grain boundary producing prehnite with a lensoid habit parallel to the host biotite cleavage. TULLOCH (1979) showed that substance migration in granitoid rocks is limited to a few milimeters during the formation of prehnite. Thus, the whole-rock system probably remained closed in terms of Rb-Sr, although altering biotites are the main carriers of the radiogenic ^{87}Sr.

When plotted in the $^{87}Sr/^{86}Sr$ vs $1/^{86}Sr$ diagram, the data points from the charnockites show no linear array, indicating that the charnockites are not a two-component mixing.

The results of the Rb-Sr measurements on the light charnockites are considered to be geologically significant. The 274 $\pm$ 17 Ma isochron is therefore interpreted as the solidification age of this rocks, concordant with other dates from the Ivrea zone which imply an important Hercynian event in this region too (PIN & SILLS, 1986; VOSHAGE et al., 1988 and others). From field evidence as well as from observations under the microscope the dark charnockite seem to be older than the light one because it is older than the main deformation of the paragneisses. The Sr isotopic compositions of the dark charnockite are significantly different from those of the light charnockite for all possible ages, implying different sources for the two groups of charnockites. Consequently, no clear explanation can be given for the dark charnockites.

5.2 The Micas from Val Strona di Postua and Val Sesia

As already mentioned in section 4.2, the biotites from Val Strona di Postua and Val Sesia scatter substantially outside the error limits. There is no obvious correlation between these single mica ages and several parameters such as:

— regional distribution
— geological or tectonic position
— altitude of the sample locality
— chemical composition of the mica and/or its host rock
— mineral fraction
— amount of common Sr or common Ar in the mica.

All these «non-correlations» exclude many possibilities (such as influence by the intrusion heat of the Main Basic Formation, tectonic movements, unequal closure temperatures for different chemical composition of the micas, supply of common Sr or Ar by fluid migration) which might explain the variation of the mica dates. We have therefore to assume that the mica ages are mixed ages, which underwent a complex process of rejuvenation.

Based on a study in the Central Alps, PURDY & JÄGER (1976) proposed the following closure temperatures by comparing mineral ages to thermodynamic data: muscovite 500 ± 50° C (Rb-Sr) and 350 ± 50° C (K-Ar); biotite 300 ± 50° C (Rb-Sr and K-Ar). The only mica samples that fit the model of PURDY & JÄGER (1976) are the micas from the pegmatite KAW 2503. K-Ar and Rb-Sr measurements of biotite yielded an age of about 211 Ma, indicating the 300 ± 50° C limit. The K-Ar muscovite age of 213 Ma indicates the 350 ± 50° C limit and the Rb-Sr muscovite age of 245 Ma the 500 ± 50° C limit (PURDY & JÄGER, 1976). The measurements were carried out on the same single crystals of about 25 cm in diameter and since neither the pegmatite itself nor the micas show any alteration these results are considered to be reliable.

A date of 211 Ma was reported by HUNZIKER (1974) on a biotite from a pegmatite near Quarona, Val Sesia, only 4 km away from the pegmatite discussed here.

Great care must be taken when interpreting the results from the measurements on the biotites from Val Sesia. It is obvious that the K-Ar ages, ranging from 188 to almost 200 Ma, are rather doubtful and an explanation must be found for this fact.

According to FLISCH (1986) a K-Ar «isochron» may be geologically significant if:

— the samples have incorporated different amounts of initial Ar, causing the spread of the sample points in the diagram;
— the «isochron» is well defined, with a correlation coefficient very close to ± 1;
— the intercept of the isochron on the y-axis shows a significant difference from the atmospheric $^{40}Ar/^{36}Ar$ ratio (which is 295.5); otherwise the isochron cannot be distinguished from an air mixture line;
— the sample points also show a linear array in the $1/^{36}Ar$ vs $^{40}Ar/^{36}Ar$ diagram and the intercept of this regression line is the same as in the isochron diagram.

If these criteria are applied to the biotites from Val Sesia (Fig. 4 and 5) their isochron age should be geologically significant, because all these criteria are met. As this isochron age coincides to a large extent with the biotite ages presented and discussed above, we assume that 211 Ma is a geologically relevant age.

This means that the single ages of the biotites are rejuvenated and do not reflect «true» cooling ages any more. In contrast, the isochron age is still preserved and the rejuvenation of the biotite single ages results in a parallel displacing of the regression line in Fig. 4 and 5. Theoretical reflection show that the parallel displacing of the regression line described here is caused by the superposition of two different effects, radiogenic Ar loss and incorporation of transported common Ar. Both effects must be connected to fluid migration.

If the age of about 211 Ma reflects the cooling down to the 300 ± 50° C limit at least for the region Val Sesia-Val Strona di Postua, then a rejuvenation mechanism is required for the biotites from the charnockite samples. These biotites seem to have been rejuvenated in the Rb-Sr as well as the K-Ar systems. Rejuvenation is caused by the formation of prehnite within the biotite grain (see also section 5.1). The prehnitization starts with a K-Ca exchange, as was shown by microprobe analyses. About half (of 140 measurements) of the biotite grains investigated revealed a CaO content > 0.4% at the expense of K_2O. This indicates that the formation of prehnite takes place in biotite grains, which are considered to be «completely fresh» under the microscope. The prehnitization causes the loss of radiogenic isotopes of both Sr and Ar from the biotite grain. Because some of the radiogenic Sr is incorporated in the newly formed prehnite the rejuvenation is systematically lower for Rb-Sr than for K-Ar (see also Table 5). The rejuvenation must be younger than the youngest biotite single age, i.e. younger than 184.4 Ma (KAW 2505).

5.3 The Micas from the upper Val Cannobina

Structurally and petrologically the pegmatites investigated from the upper Val Cannobina belong to the same suite. As a pegmatite bearing primary muscovite requires crystallization at a minimum pressure of ~3.8 kbars (ESSENE, 1982), the pegmatites must have been intruded at a depth greater than 12 km. If we assume a geothermal gradient of 30° C/km or more the temperature of the country rocks must have been higher than the blocking temperature of muscovite at the time of intrusion of the pegmatites. The cooling history of the pegmatites thus represents the cooling history of the country rocks too.

Except the fraction > 10 mesh of sample KAW 2722, which possibly has a slight Ar overpressure, the muscovites in Val Cannobina have consistent cooling ages of about 175 Ma. The sample KAW 2725 has an intense intergrowth of sillimanite and muscovite, which were not separable, so that we had to take a muscovite-sillimanite mixture of less than 4% potassium for argon analyses. In spite of these difficulties the resulting age of 174.8 Ma shows that sillimanite does not have any potassium nor excess argon.

A clear correlation exists between the age of the biotites and the degree of chloritization: the age decreases as the amount of chlorite increases. The highest biotite age, 157 ± 2 Ma (KAW 2724), thus gives a minimum age for the cooling to 300 ± 50° C (PURDY & JÄGER, 1976); the lowest, 121 ± 1.3 Ma (KAW 2723), gives a maximum age for the act of rejuvenation. This may actually have taken place during the Paleocene (STÄHLE et al., 1986).

5.4 The Fission Track Ages from the upper Val Cannobina

A fission track zircon age of 48.2 ± 3.7 Ma from Porto Ronco close to the Insubric line (HURFORD, 1986) is significantly younger than the zircon FT age of 63.3 ± 3.6 Ma (1 σ) from 6 km south of the Insubric line and may indicate that the Southern Alps (at least the parts close to the Insubric line) were influenced by the Tertiary thermal overprint of the Central Alps.

Since the older zircon may also have been rejuvenated, 63.3 ± 3.6 Ma (1 σ) is considered a minimum age for the cooling down to 220 ± 20° C.

It is also possible that the different zircon FT ages record Alpine tilting of the Ivrea zone. More FT dating need to be done to decide what really happened.

The apatites from the Southern Alps and the Sesia zone are within the error-margin of the same age of 12.5 ± 2 Ma (1 σ) for the cooling to 100 ± 20° C (Table 7). They are similar to the data given by WAGNER & REIMER (1972). This indicates that there has been no vertical displacement along the Insubric line since the Middle Miocene, although lateral movements may still have taken place (S. SCHMID et al., 1987). The sample from the Monte Rosa Steep Belt (KAWQ 2737) is noticeably younger, 10.8 ± 0.8 Ma (1 σ). Longer lasting vertical movements can be postulated along the steep belt of the Pennine nappes associated with the uplift of the Central Alps.

A mean apatite track length of 13.25 ± 1.4 μm indicates a rather slow cooling rate (about 8° C/Ma) for the Sesia zone and the Southern Alps in the area investigated.

6. Conclusions

From the U-Pb zircon and monazite data of KÖPPEL (1974) and KÖPPEL & GRÜNENFELDER (1979), the Pb-Pb data of CUMMING et al. (1987) the Sm-Nd data of BEN OTHMAN et al. (1984), VOSHAGE et al. (1987), VOSHAGE et al. (1988) and the 274 Ma whole-rock isochron presented in this paper it is tentatively concluded that the main high-grade metamorphic event in the Ivrea zone occurred during Hercynian time.

The history of the basic and ultrabasic rocks of the Ivrea zone is in fact very complicated and not yet completely understood (see for example PIN & SILLS, 1986; CUMMING et al., 1987; VOSHAGE et al., 1987; VOSHAGE et al., 1988), but from the data of PIN (1986) and the above-mentioned authors a Hercynian intrusion age for at least some important parts of the Main Basic Formation is implied too. Mica ages between 245 Ma and 210 Ma in Val Sesia and Val Strona di Postua as well as mica ages of 182 Ma to 121 Ma in Val Cannobina presented here allow a more precise look into the cooling history after the Hercynian temperature maximum, but no information is obtained on the evolution before the Hercynian period.

The Rb-Sr and K-Ar mica ages of this paper seem to indicate that at least the SW part of the Ivrea zone had cooled down to 300° C ~210 Ma ago, which is significantly

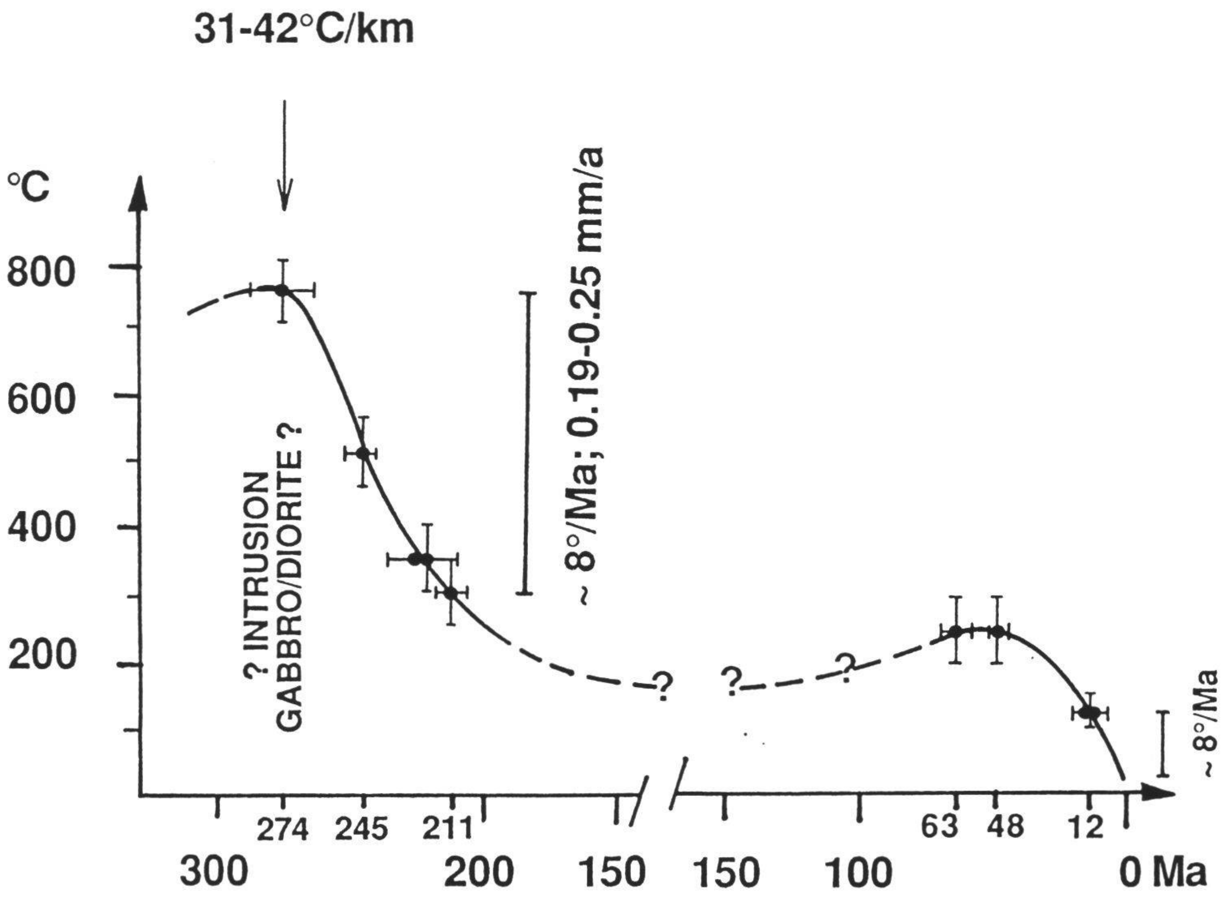

Figure 6: Time-temperature evolution of the Ivrea zone since the Hercynian metamorphic peak based on data in this paper. The left part of the diagram shows the cooling to about 300° C for the Val Sesia/Val Strona di Postua area. The right part of the diagram shows the Alpine cooling history for the Val Cannobina region. As mentioned in the text the course of temperature between ~ 170 and ~ 65 Ma b.p. is not yet known.
The data of this paper indicate that we cannot postulate an uniform cooling history for the whole Ivrea zone.

faster and earlier than assumed until now (see Fig. 6). The considerably lower ages of the micas in the Val Cannobina region indicate that deeper crustal levels must have been brought up to the surface by faster uplift since at least 175 Ma. A comparison of the cooling history from the two areas investigated shows the following: in the SW part the metamorphic peak was followed by a cooling to 300° C with a cooling rate of about 8° C/Ma. We cannot work out, if the NE part went through the same cooling at that time. But it is certain, that later the uplift in the NE was faster, so that today deeper (and? therefore younger) crustal levels are cropping out. An uplift history that has not been uniform along the Ivrea zone is discussed by SILLS (1984) based upon differing pressure estimates along the strike. There is another possibility to explain the lower mineral ages in the north-eastern part of the Ivrea zone: according to HANDY (1987) there must have been a considerable narrowing of the isotherms due to the crustal thinning. Accordingly, the Val Cannobina area must have been in a domain with a higher geothermal gradient than Val Sesia and Val Strona di Postua. Keeping in mind the pressure increase from SW to NE, which cannot be explained by crustal thinning, we favour the first of these two possibilities to explain the lower mineral ages in the NE.

The distribution picture of the mica ages from the literature (JÄGER et al., 1967; HUNZIKER, 1974; BORIANI et al., 1987) and from the present study shows an increase from NW to SE (i.e. perpendicular to strike). This must mean that the tilting of the Ivrea crustal block into its present subvertical position took place after the cooling down to 300° C. Tilting may have occured during the Alpine orogeny, as suggested by S. SCHMID et al. (1987) based on paleomagnetic investigations indicating a 60°-85° rotation around a subhorizontal axis (HANDY, 1987).

Because our FT data indicate a contemporaneous uplift of the area investigated between the Sesia zone and the Serie dei Laghi (see Chapter 5.3) since the Middle Miocene, the tilting of the Ivrea zone is older than 12 Ma.

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KAW No	1782	1784	2504	2505	2506	2507
Weight-%						
SiO2	69.20	59.76	68.67	60.89	67.39	68.66
TiO2	0.36	0.87	0.43	0.99	0.55	0.37
Al2O3	15.21	17.08	15.06	16.74	16.01	15.69
Fe2O3	0.43	0.85	0.62	1.52	0.41	0.49
FeO	2.29	5.15	2.62	4.60	3.21	2.05
MnO	0.04	0.10	0.06	0.11	0.07	0.04
MgO	1.22	3.20	1.00	2.54	1.84	1.21
CaO	2.82	5.33	2.90	5.21	3.61	3.26
Na2O	3.54	4.08	3.24	3.59	3.79	3.18
K2O	3.56	1.62	3.57	1.96	1.79	3.51
P2O5	0.07	0.28	0.11	0.29	0.07	0.07
H2O+	0.38	1.23	0.40	0.79	0.40	0.47
Total	99.12	99.55	98.68	99.23	99.14	99.00
ppm						
Ba	1009	544	903	713	564	1406
La	24	52	36	42	34	35
Y	27	28	35	25	31	15
Zr	140	162	178	176	152	149
V	42	130	37	138	70	47
Cr	19	67	< 10	33	26	15
Zn	56	117	75	106	75	55

Appendix 1:
XRF analyses of the Val Strona di Postua charnockite whole-rock samples. KAW 1782, 2504, 2506, 2507: light coloured charnockites; KAW 1784, 2505: dark charnockites.

Buchbesprechung

Cretaceous of the Western Tethys (1989)

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Dieser gut illustrierte Band enthält die Berichte des dritten internationalen Kreide-Symposiums, das 1987 in Tübingen stattfand. Das Werk ist der 1987 verstorbenen Tove Birkelund gewidmet, die als dänische Geologin, Wissenschaftlerin und Professorin viel zur Erweiterung der Kenntnis der Kreidestratigraphie und -Paläontologie von Grönland und Dänemark beigetragen hatte.

Die thematische Aufteilung der beinahe 50 verschiedenen Beiträge von über 100 Autoren erfolgte in folgenden Kapiteln: -Westliches Mittelmeergebiet-Alpen, Karpathen, Dinariden und Kaukasus-Teilaspekte von Grenzregionen-Biostratigraphie, Korrelation und Paläogeographie-sowie Vulkanismus und Magneto-Stratigraphie. Das Thema wird hier in modernen, wissenschaftlichen Abhandlungen in sehr anregender und gut dokumentierter Weise zusammengestellt.

Gabriel Wiener