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LATE PALEOZOIC PLUTONISM IN THE EASTERN ALPS

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Introduction

Granitoid gneisses with late Paleozoic intrusion ages turn out more and more to be an extraordinary typical constituent of the Alpine-Carpathian basement. They are known to occur in numerous bodies over the entire length of the Alpine-Carpathian arc, from the French Alps down to Slovakia. In the Austrian Alps, more than 20 % of the exposed pre-Mesozoic crust is built up of such granitoids, and they form metaplutonic complexes of considerable extent in the lower Penninic unit and the structurally higher Austroalpine nappe system.

The four main metaplutonic terrains of the **Austroalpine realm** are (from east to west) the *Raabalpen-Semmering-Wechsel complex*, located between Vienna and Graz, the *Gleinalm complex* west of Graz, the *Seckau-Bösenstein complex* of northern Styria, and the *Schladminger Tauern complex*, which is situated ca. 70 km SSE of Salzburg (Fig.1).

The largest and so far best understood metaplutonic terrain of the Eastern Alps is, however, exposed in the **Penninic Tauern Window** (*Hohe Tauern Batholith*). It can be divided into three largely independent sectors, a western, a central and an eastern sector, each consisting of somewhat different suites of granitoids (Fig.1).

The eastern sector of the Hohe Tauern Batholith lies along the excursion route, which is described in the second part of this excursion guide.

Granitoid types

It has been pointed out recently by Finger and Steyrer (1990) that the Late Paleozoic plutonism of the Alps has chemically much in common with the calc-alkalic plutonism of continent margin orogenic belts. This appears to be especially valid for the Austrian Alps: Here, typical calc-alkaline tonalite-granodiorite-granite associations are present in all major regional plutonic complexes. The granitoids are, with only few exceptions, sodium-rich and metaluminous to weekly peraluminous rocks, and therefore I-type granites (s.l.) in terms of the Australian classification (Chappell and White, 1974). Furthermore, nearly all of the granitoids display the characteristic trace element signatures of volcanic-arc granites in the sense of Pearce et al. (1984). The ε_{Nd} - ε_{Sr} covariations are also in the typical range of continental margin I-type batholiths, indicating involvement of sources with mantle isotopic composition and mature crustal sources (cf. Figs. 2,3).

Current work in the **Hohe Tauern Batholith** (Haunschmid et al., 1991; Schermaier, 1991; Finger et al., 1992) has revealed the presence of at least three different suites of I-type granitoids:

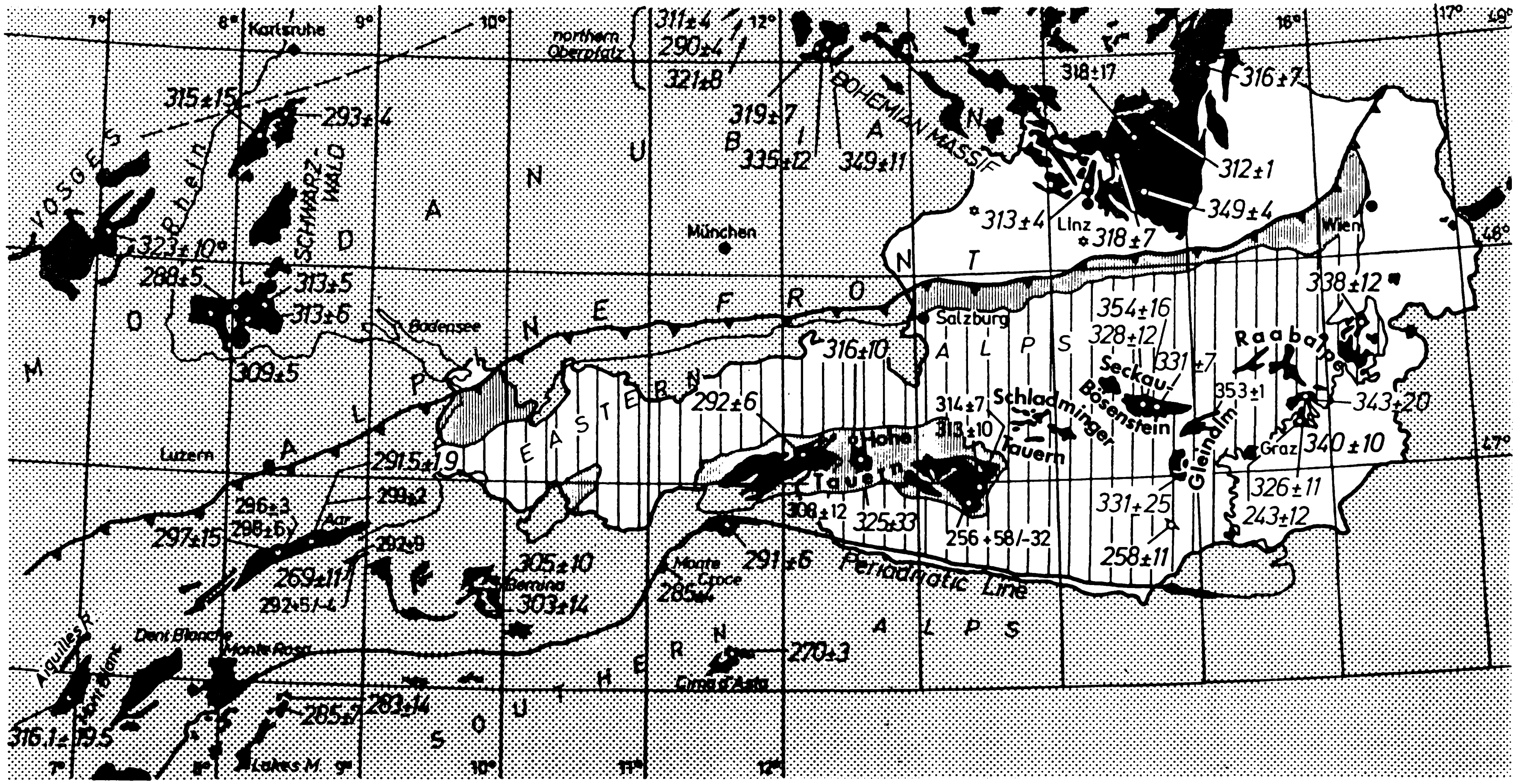

Fig.1: Distibution of late Paleozoic granitoids (black) in Austria and neighbouring areas (map slightly modified after Finger and Steyrer, 1992). Shown age data refer to published Rb-Sr WR ages (big numerals) and U/Pb ages (small numerals). Tectonic subdivision of Alps in Austria: wide vertical hatching = Austroalpine, narrow hatching = Penninic (partly Helvetic).

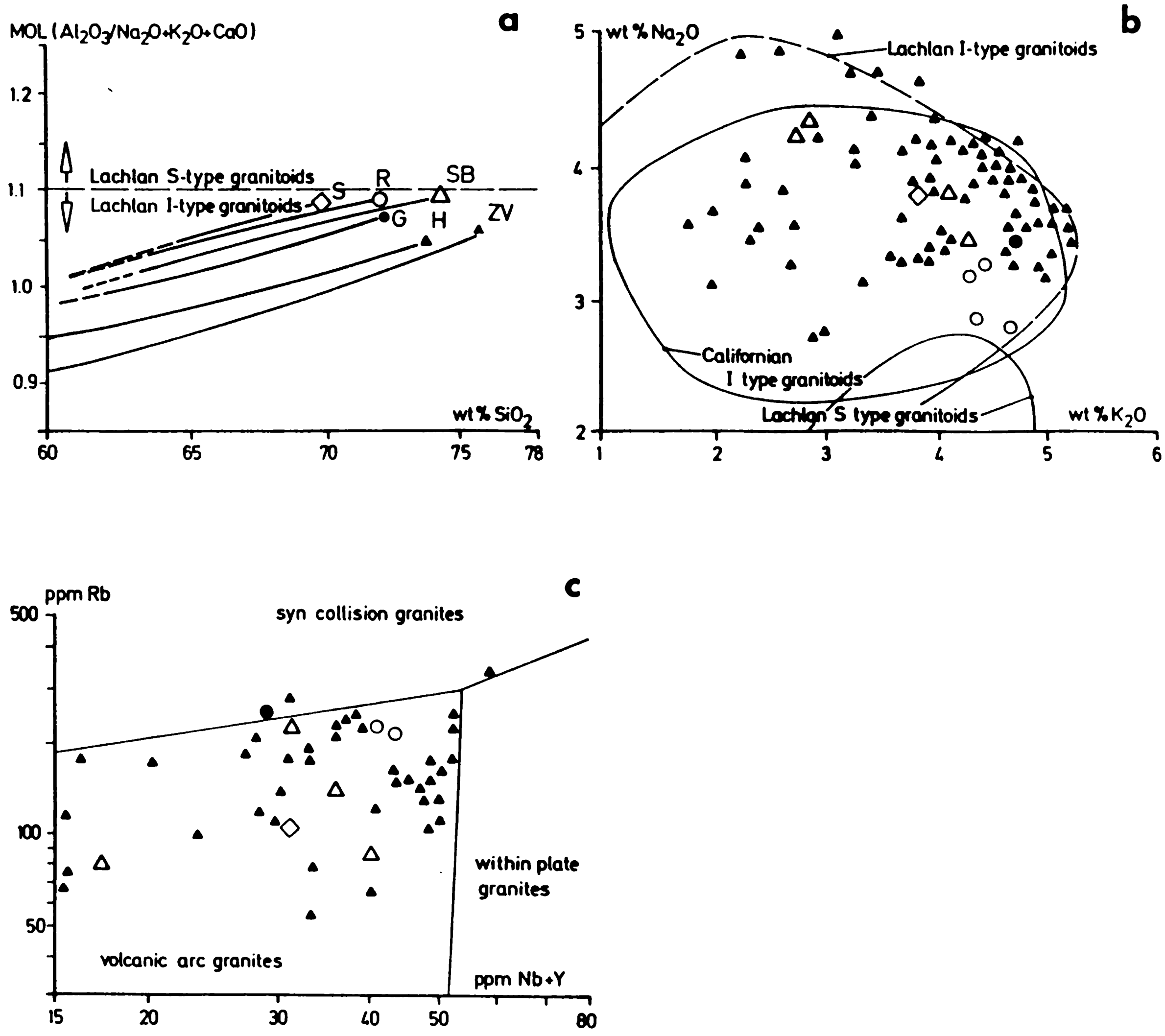

Fig.2: Three conventional diagrams for the classification of granitic rocks with plots and trends of the intra-Alpine late Paleozoic granitoids of Austria. Fig. 2C is after Pearce et al. (1984). Black triangles: Hohe Tauern Batholith (undiff.). Other symbols see Fig.5. Fields of Lachlan and Californian granites after Finger and Steyrer (1990) and references therein.

The *Zillertal-Venediger Suite* of the western Tauern Window and the *Hochalm Suite* of the eastern Tauern Window are typical calc-alkaline suites and they both comprise a wide variety of granitoids, ranging from medium grained tonalitic rocks over granodiorites to (sometimes coarser grained) granitic end members. Together these calc-alkaline rocks make up ca. 80 % of the Hohe Tauern Batholith.

The Zillertal-Venediger Suite is tonalite-granodiorite dominated. It follows a trondhjemitic differentiation trend (Lameyre and Bowden, 1982) and appears to be chemically quite primitive, with high CaO and low K_2O, Sr, Ba and Rb contents (Figs.4,5; Tab.1).

The Hochalm Suite is on average more felsic and granodiorite-granite dominated. In the Streckeisen diagramm (Fig.5), it spans a calc-alkaline granodioritic trend in the sense of Lameyre and Bowden (1982). When compared to the Zillertal-Venediger Suite, the Hochalm Suite is considerably lower in CaO, but higher in alkalies, Sr and Ba, at a given SiO_2. (Figs.4,5; Tab.1).

A third suite can be roughly outlined as *high-K_2O I-type granitoids*. These rocks are volumetrically of minor importance and make up not more than 20 % of the Hohe Tauern Batholith. However they can be found in every sector (e.g. Romate gneiss, see Stop 00). They are always coarse grained and range in composition from syenitic over monzonitic and monzodioritic to granitic. Major element chemistry is usually metaluminous (therefore: I-type) and only moderately felsic with SiO_2

contents between 60 and 68 %. In their trace element spectrum, the rocks are distinctly enriched in Rb, Ba, Sr, Th and Zr (Fig.4).

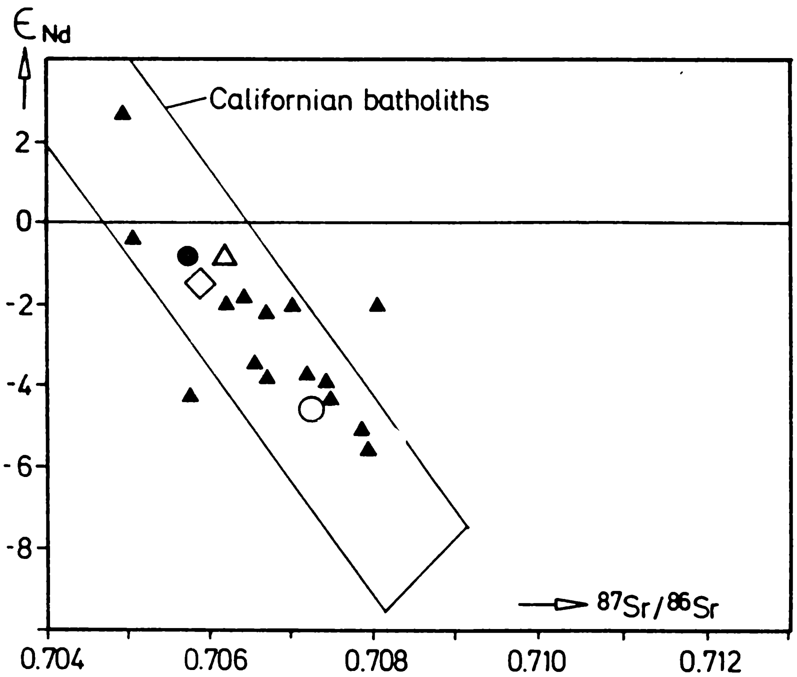

Fig.3: $^{87}Sr/^{86}Sr$ vs ε_{Nd} diagram with model initial ratios of intra-Alpine granitoids. Black triangles: Hohe Tauern Batholith (undiff.). Other symbols as in Fig.5. Field of Californian batholiths after De Paolo (1981).

Where contacts to the calc-alkaline intrusions are exposed, the high-K_2O granitoids were always found to be older. Furthermore, the high-K_2O granitoids very often turned out to be closely associated with meta- to diatectic country rocks. This implies that they were formed during large scale crustal anatexis, which obviously stood at the beginning of the evolution history of the Hohe Tauern Batholith. Geochronological data suggest an age between 330 and 310 Ma for this anatectic event, while the bulk of the calc-alkaline granitoids intruded probably between 315 and 290 Ma (see review of age data in Finger et al., 1992). Unlike the high-K_2O group, the calc-alkaline intrusions solidified usually as high level plutons. This means that the migmatitic crust was uplifted and cooled in the meantime.

Apart from the three I-type granitoid suites mentioned above, the Hohe Tauern Batholith comprises also some minor plutonic bodies of granitoids with affinities to *S-type* and *A-type* granites.

The most important example of an S-type granite suite is the Granatspitz massif of the central Tauern Window, which consists mainly of a leucocratic, medium to coarse grained and more or less porphyritic two mica metagranite with pseudomorphs after cordierite. The granite is likely to have formed during the same anatectic event which generated also the high K_2O I-type granitoids.

Those granites considered to approach A-types in composition, are usually small leucocratic intrusions, which have been found throughout the batholith to crosscut the calk-alkaline granitoids (see Stop 00, Haunschmid et al. 1991). Maybe, an early Permian age should be envisaged for them (Vavra, 1989; Vavra and Hansen, 1991). The most distinctive features of the "A-type" granites lie in their trace element spectrum, which shows systematic enrichment in Y and HREE and a distinct negative Ba and Eu anomaly (see Fig.4, Tab.1).

Although only relatively little data are presently available from the **Austroalpine realm**, there is some evidence that granite typology in that area is in many ways similar to the Hohe Tauern Batholith. Clearly, the bulk of the granitoids belongs again to calc-alkaline I-type suites.

For the *Seckau-Bösenstein area*, it has been already stated by Metz (1976) that the dominant plutonic lithology is tonalitic/granodioritic, associated with minor amounts of diorites and gabbros (Fig.5). Our preliminary set of chemical data suggests that many plutonic

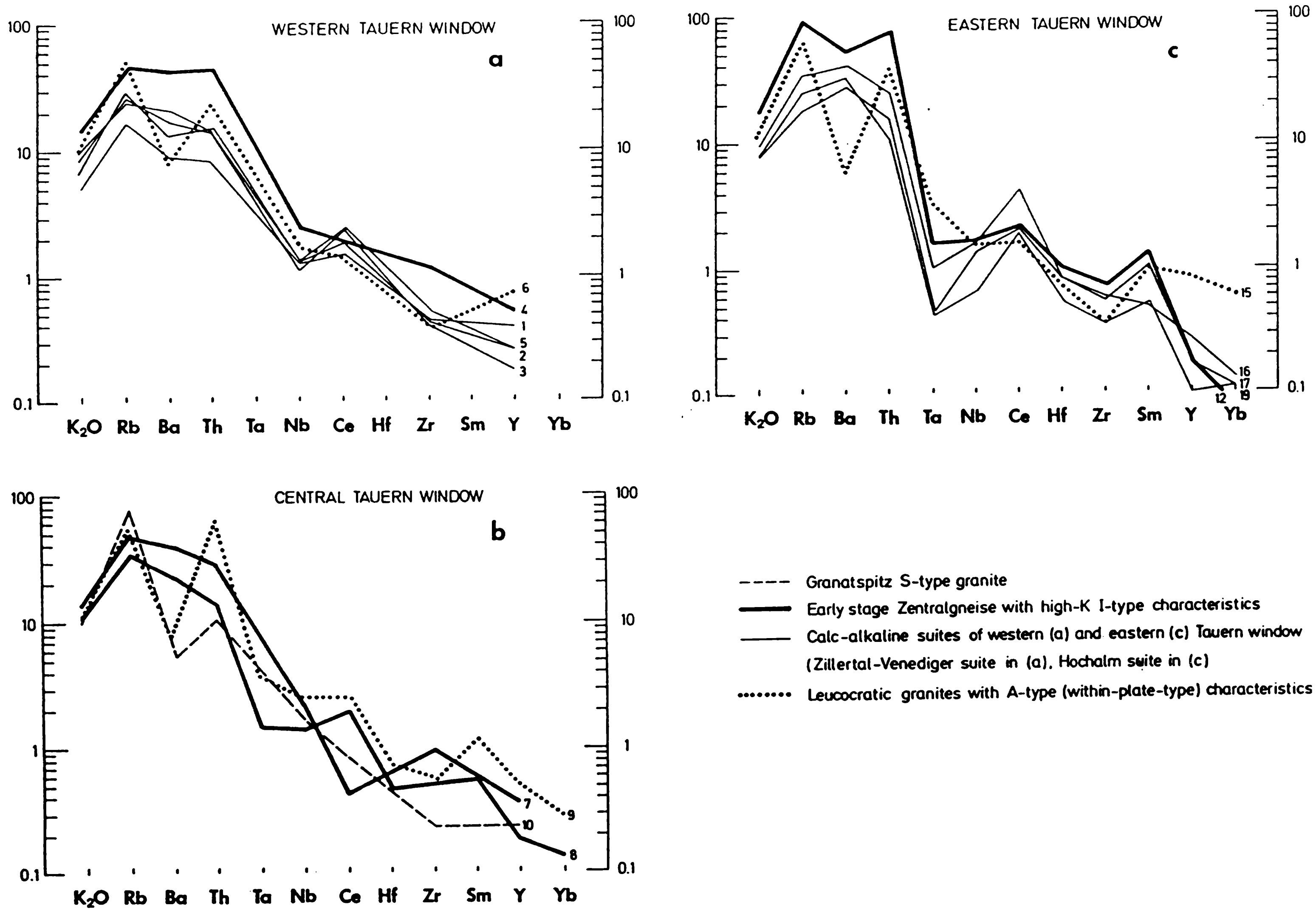

Fig.4: HORG-normalized trace element patterns of different granitoid suites of the Hohe Tauern Batholith (HORG = hypothetical ocean ridge granite, see Pearce et al. 1984). Sample numbers and locations see Tab.1.

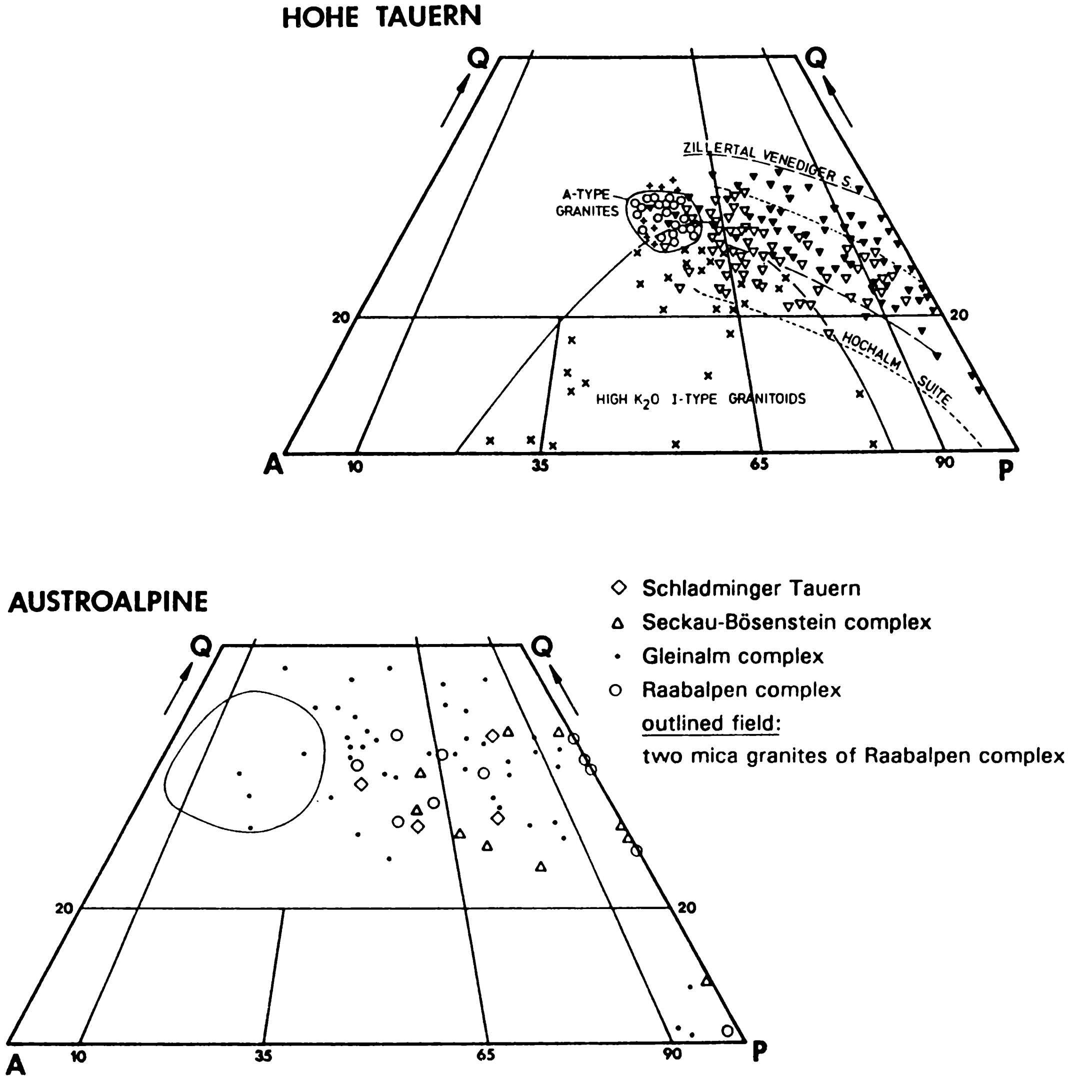

Fig.5: Streckeisen diagrams with plots of intra-Alpine granitoids. Data sources: Finger et al. (1992 and references therein), Formanek (1964), Metz (1976), Neubauer (1988), Peindl et al. (1990), Wieseneder (1968) and unpublished University of Salzburg data.

rocks of the Seckau-Bösenstein area are compositionally quite similar to the Hochalm Suite of the Eastern Tauern Window (see Tab.1).

The same seems to be valid for the *Schladming complex*, as far as we can conclude from the few presently available data (Fig.5, Tab.1).

The *Gleinalm complex* was investigated by Neubauer (1988) and found to consist dominantly of granodiorites and granites, but also of some tonalites and diorites (Fig.5).

For the *Raabalpen-Semmering-Wechsel complex*, new data have been recently presented by Peindl et al. (1990). These imply the presence of a calc-alkaline suite with trondhjemitic differentiation trend. Furthermore, Peindl et al. (1990) described a distinct group of very felsic two-mica granites (Fig.5), which could be similar to the A-type granites of the Hohe Tauern Batholith.

An important but as yet not completely resolved question is, whether the Austroalpine plutonic complexes are of the same age as the Hohe Tauern Batholith or not. Presently available Rb-Sr isotope data (Fig.1) seem to indicate that they are slightly older. However, more data, including high quality zircon data, will be necessary to work out the overall timing of the Late Paleozoic plutonism of the Austrian Alps.

		HOHE TAUERN											SCHLADMINGER TAUERN	SECKAU BÖSENSTEIN		
		high K_2O I-type granitoids			Granatsp. massiv	Zill.- Venediger suite		Hochalm suite		A-type granitoids						
	Nr.:	4	7	12	10	1	5	16	18	20	15	6	21	22	23	24
	SiO2	60.85	62.37	62.39	74.28	60.73	73.93	60.60	70.20	73.23	74.54	75.22	70.08	63.63	67.55	71.56
	TiO2	0.76	0.65	0.54	0.12	0.57	0.23	0.48	0.23	0.27	0.21	0.13	0.36	0.75	0.55	0.35
	Al2O3	15.80	17.86	15.83	14.64	16.40	14.30	18.39	15.20	13.85	13.12	13.45	14.95	16.66	15.90	14.57
	FeOtot	5.20	3.20	2.40	1.22	6.55	1.89	4.24	1.67	1.89	1.49	1.52	2.52	4.45	3.22	2.35
	MnO	0.08	0.05	0.05	0.07	0.20	0.00	0.23	0.04	0.02	0.05	0.07	0.06	0.09	0.06	0.06
	MgO	3.87	1.92	1.61	0.29	3.34	0.33	2.43	0.45	0.28	0.29	0.23	0.88	2.17	1.25	0.84
	CaO	2.93	2.58	2.21	0.73	5.82	1.40	3.98	1.96	1.25	1.17	0.88	2.03	3.59	2.72	1.67
	Na2O	3.35	3.88	3.87	3.21	3.08	4.73	4.64	4.32	3.69	3.23	3.90	3.72	4.18	4.20	3.80
	K2O	5.61	5.31	7.05	4.94	1.98	3.48	3.16	3.30	4.73	4.68	4.50	3.95	2.72	2.84	4.02
	P2O5	0.57	0.26	0.50	0.26	0.24	0.07	0.36	0.10	0.08	0.05	0.01	0.19	0.28	0.21	0.15
	L.O.I.	0.70	1.86	1.84	0.89	1.08	1.02	1.50	1.60	0.87	0.82	1.28	0.80	0.80	0.80	0.80
	tot	99.72	98.94	98.29	100.65	99.99	101.38	100.01	99.07	100.16	99.65	101.19	99,54	99.32	99.30	100.17
	A/CNK	0.93	1.06	0.88	1.22	0.92	1.01	1.01	1.07	1.03	1.05	1.04	1.06	1.02	1.07	1.07
XRF	Nb	24	22	17	15	13	13	14	bdl	16	15	17	11	12	9	13
XRF	Zr	380	315	244	78	152	164	200	142	189	125	123	171	246	230	161
XRF	Y	35	24	12	16	27	18	19	11	47	58	49	20	28	8	23
XRF	Sr	347	450	1074	70	287	128	882	520	119	92	84	305	645	530	286
XRF	Ba	1970	1775	2736	264	456	812	1492	1127	511	197	389	1111	1023	1031	909
XRF	Rb	182	188	368	285	65	102	108	117	244	281	195	105	84	81	139
XRF	Cr	127	55	37	bdl	17	bdl	49	bdl	3	bdl	1	104	102	167	179
XRF	Ni	47	23	40	10	11	1	23	bdl	16	20	10	7	10	7	8
XRF	Th	33	22	55	8	6	11	13	19	20	31	17	11	6	8	8
INAA	Ba	-	1735	2632	-	382	774	1609	1018	601	273	-	-	-	-	-
INAA	Rb	-	192	356	-	60	105	98	100	244	257	-	-	-	-	-
INAA	Cr	-	29	35	-	23	2	10	3	3	4	-	-	-	-	-
INAA	Th	-	23	58	-	6	11	9	9	23	31	-	-	-	-	-
INAA	U	-	4.9	12.3	-	1.1	2.6	3.0	2.3	10.3	15.0	-	-	-	-	-
INAA	Hf	-	9.0	9.1	-	4.8	6.5	7.4	3.0	7.6	6.2	-	-	-	-	-
INAA	Sc	-	6.9	7.3	-	20.0	4.0	4.8	3.1	5.3	4.8	-	-	-	-	-
INAA	Co	-	9.4	7.7	-	17.0	2.2	7.9	1.8	2.3	2.0	-	-	-	-	-
INAA	Ta	-	1.64	1.12	-	0.85	0.85	0.31	1.01	2.30	2.30	-	-	-	-	-
INAA	La	-	42.2	36.7	-	27.6	34.2	46.0	31.5	40.5	25.6	-	-	-	-	-
INAA	Ce	-	76.4	77.1	-	51.5	62.9	75.1	57.5	81.4	55.5	-	-	-	-	-
INAA	Nd	-	34.4	46.3	-	22.8	24.2	23.0	21.6	34.4	28.5	-	-	-	-	-
INAA	Sm	-	6.94	11.72	-	6.70	5.15	4.38	3.77	10.76	9.15	-	-	-	-	-
INAA	Eu	-	1.92	1.95	-	1.41	0.80	1.31	1.02	0.94	0.46	-	-	-	-	-
INAA	Tb	-	0.74	0.48	-	0.73	0.55	0.34	0.36	1.16	1.14	-	-	-	-	-
INAA	Yb	-	2.17	0.60	-	2.35	1.80	1.09	0.90	4.22	4.95	-	-	-	-	-
INAA	Lu	-	0.32	0.12	-	0.37	0.28	0.18	0.15	0.60	0.68	-	-	-	-	-
	εNd(320)	-	-4.63	-4.39	-4.83	-3.78	-1.66	-1.94	-	-1.18	-3.98	-2.25	-1.38	-	-0.94	-4.08

Tab.1: Representative XRF and INNA analyses of selected late Paleozoic granitoids of the Austrian Alps. A/CNK= mol $Al_2O_3/(CaO+Na_2O+K_2O)$.Sample locations:

1 - metatonalite, southern rim of Venediger core; 4 - biotite-rich Augen gneiss, inner Krimml valley; 5 - "Augen- und Flasergneis", mittlere Gfrorene Wand Spitze, near Olperer; 6 - "Augen- und Flasergneis", quarry in the outermost Obersulzbach valley; 7 - Hochweißenfeld gneiss, S of Abretterkopf; 10 - metagranite, W Tauernmoos lake; 12 - Romate gneiss, near Mallnitz; 15 - leucogranite, tunnel from Gastein valley to Mallnitz; 16 - "Hochalmporphyrgranit", NNW Hochalmspitze, near Osnabrücker Hütte; 18 - Malta tonalite, Malta valley, bifurcation to Katowitzer Hütte; 20 - leucogranite, Gößbach valley, Untere Thomanbauernalm; 21 - Schladming granite gneiss, Pötten; 22 - metagranodiorite, Bösenstein, Mühle St. Johann; 23 - Kraubath orthogneiss, Pressnitzgraben; 24 - Seckau granite, Rannachgraben.

Geodynamic interpretation of the Late Paleozoic I-type plutonism in the Alps

During the past years, several attempts were made to fit the intra-Alpine basement into an overall Variscan plate tectonic concept (e.g. Frisch and Neubauer, 1989; Frisch et al., 1990). Generally, there is agreement on the point that the Paleozoic units of the Alps were once situated somewhere along the southern flank of the Variscan orogen (see e.g. Franke, 1989). However, the locations of single units relative to each other and to the actual Variscides on the north of the Alpine front (e.g. the Moldanubian unit; see Fig.1) prior to the Alpine tectonics can be only very tentatively inferred, and the evolution and paleogeography of the Alpine basement during and before the Variscan Gondwana-Laurasia continent collison event, which started in the Devonian (Matte, 1986) is still more uncertain.

Frasl (1987) stressed pronounced lithological contrasts between the Moldanubian zone of the Bohemian Massif (Fig.1) and the Paleozoic formations of the Tauern Window and emphasized that most of the intra-Alpine Variscan units are obviously not the simple straightforeward continuation of the Moldanubian zone. Considering the important dextral shearing event, that affected much of the central European crust at the end of the Variscan orogeny (Arthaud and Matte, 1977), it appears to be quite possible that the intra-Alpine Variscan units of Austria were formerly situated much more to the southeast of the Bohemian massif.

However, like the southern (extra-Alpine) Variscan units of western Europe, the Alpine basement comprises fragments of ophiolites (see e.g. Neubauer et al., 1989), which are remnants of early Paleozoic or late Proterozoic oceanic domains extending in the Gondwana foreland. Furthermore, Frisch and Neubauer (1989) presented convincing evidence that these oceanic domains were strongly shortened (Early Carboniferous) and at least partly closed by northward subduction in the course of the Variscan convergence of Gondwana and Laurasia, just like their counterparts in western Europe (Matte, 1986). Frisch and Neubauer (1989) also proposed that, along with this process, Gondwana derived terranes attached from the south stepwise to the Variscan orogen.

Certainly, it would be most tempting to relate the calc-alkaline I-type plutonism of the Alps to such a subduction scenario along the southern Variscan fold belt flank. On the other hand, there is faunal, facies and paleomagnetic evidence that the megacontinents Gondwana and Laurasia were long linked and formed a nascent Pangea, when the late Paleozoic I-type plutonism occurred in the Alps (see e.g. review in Neugebauer, 1988). Consequently, one might argue that the plutonism is rather collision- than subduction-related, and that its I-type features are merely a consequence of a collision-induced anatectic remagmatization of infra-crustal I-type sources, e.g. volcanic arc material of older sutures (see e.g. Vavra, 1989).

It is , however, still an open question, how the Alpine units were actually involved in the Variscan megacontinent collision event. Namely, it appears possible that they were situated in a southeastern section of the Variscan fold belt, where Gondwana and Laurasia did not fully touch and where previous oceanic domains between these continents remained open. Thus, a continental margin type orogeny might have survived in this southeastern realm from the early to the late Paleozoic, while the actual Variscan continent collision, i.e. the docking of the megacontinents, was restricted to the western sector of the Variscan belt (see also Ziegler, 1986).

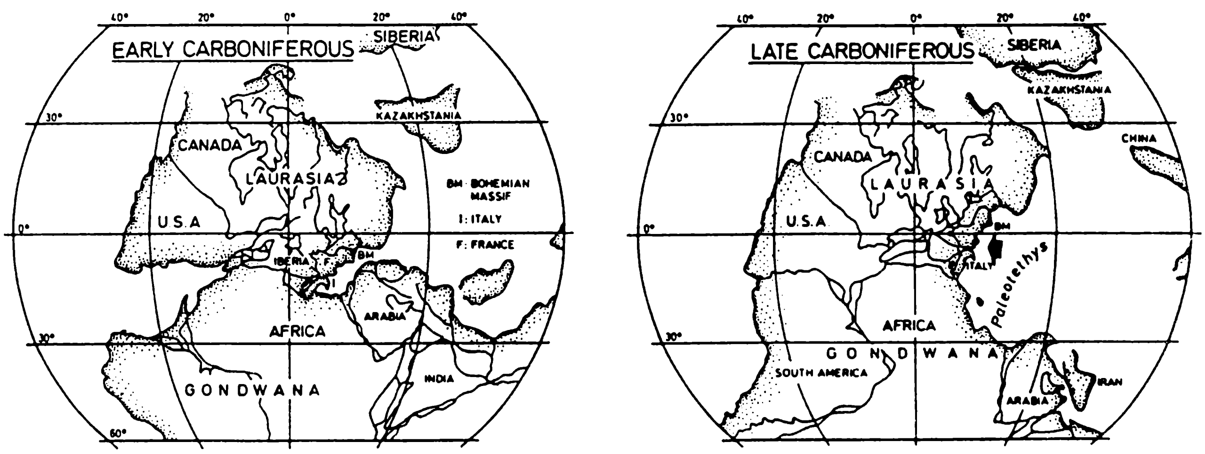

Fig.6: Paleogeographic base maps for the early and late Carboniferous after Scotese (1984). Finger and Steyrer (1990) hypothesized that the palaeo-Tethys ocean was subducted in the late Paleozoic below the Variscan fold belt, which is in front of the northern Laurasian part of the nascent Pangea megacontinent (black arrow). This plate configuration probably formed first in the course of the Carboniferous westward drift of Gondwana relative to central Europe. The map for the early Carboniferous suggests a more or less intracontinental position of the Variscan fold belt between Gondwana and Laurasia.

Finger and Steyrer (1990) have argued that the well documented late Paleozoic west drift of Gondwana relative to Laurasia and the simultaneous opening of the Pangea golf (Arthaud and Matte, 1977) could have resulted in a marked "post-collisional" Cordilleran type orogeny along the southern flank of the Variscan orogen, giving rise to a vast production of granitoids (Fig.6). One argument in favour of such a concept is that the Variscan orogen exhibits a significant active continent margin type zonation of its late stage granitoids with a southern belt of predominantly I-type plutons in the Alps (outer arc ?) and a northern belt of predominantly S-type plutons (inner arc ?) in the Moldanubian unit.

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