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VEGETATION ON ANTHROPOGENIC METALLIFEROUS SOILS IN THE EASTERN ALPS

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Abstract: A syntaxonomic revision of vegetation of anthropogenic metalliferous habitats (mine spoils of lead, zinc and copper mining) in the Eastern Alps (Austria, Germany, Italy and Slovenia) was made. The communities studied belong to the *Thlaspietea rotundifolii* (*Linaria alpina-Cerastium uniflorum* comm., *Papaveri kerneri-Thlaspietum kerneri*, *Violetum dubyanae*, *Thlaspietum cepaeifolii*, *Thlaspietum rotundifolii*, *Scrophulario juratensis-Erysimetum sylvestris*, *Minuartia gerardii-Silene glareosa* comm., *Epipactido atrorubentis-Silenetum glareosae* and *Sileno alpestris-Moehringietum muscosae*) and to the *Asplenietea trichomanis* (*Sileno rupestris-Asplenietum*). There is neither floristic support nor syntaxonomic justification for the concepts of the *Galio anisophylli-Minuartion vernae*, the *Violetalia calaminariae* and the *Violetea calaminariae* in the Eastern Alps. These units should be included within the *Thlaspion rotundifolii*, *Thlaspietalia rotundifolii* and *Thlaspietea rotundifolii*, respectively.

INTRODUCTION

Soils covering ore-bearing rock or slag heaps contain heavy-metal ions, both micronutrients as well as elements not essential to plants, in excessive amounts. Under those conditions most plants show physiological and morphological effects such as enzyme inactivation, reduced growth and resulting stunted stature and only those plants which are resistant to heavy metal toxicity can colonise such habitats. The term heavy-metal "resistance", as opposed to "tolerance" (see LEVITT 1972, PUNZ & KOERBER-ULRICH 1993), does not imply a single mechanism, but encompasses a number of ecological adaptations, such as exclusion of ions, biochemical changes of root surface, compartmentation (into cell wall or vacuole) or binding to appropriate substances (e.g. metallothioneins; STEFFENS 1990), secretion, deposition, and production of new accumulation organs (FOY et al. 1978, LARCHER 1980, BRADSHAW & MCNEILLY 1981, WOOLHOUSE 1983, SCHLEE 1986). Terms such as metallophytes ("Erzpflanzen") confined to metalliferous soils, facultative metallophytes (or pseudo--metallophytes), and non-resistant plants have been coined to cover the scale of metal tolerance of plants (e.g. GAMS 1966, ANTONOVICS et al. 1971, ERNST 1990).

Those metallophytes which show metal "hyperaccumulation", i.e. concentrations of more than 1000 mg of metal per kg of dry weight (ANTONOVICS et al. 1971, ERNST 1976a, 1982,

PROCTOR & WOODELL 1975, LARCHER 1980, BROOKS 1987, PUNZ 1995), have long been used as indicators in ore prospecting. Although some species on metalliferous soils are considered to be glacial relics (see ERNST 1990 for a review), there is no doubt that the ability to develop heavy-metal resistance is genetically controlled and modified by adaptation over short periods of time (ERNST 1974, 1990, BRADSHAW & MCNEILLY 1981, LARCHER 1980).

The toxicity of soil detrimental to seed establishment and plant growth fosters the development of special plant communities. The vegetation of metalliferous soils is dominated by low-growing forbs and grasses. The coarse-patchiness (formation of large monospecific patches alternating with bare ground) is a striking synmorphological feature of such communities and is a result of space-limited dispersal of clonal species. Of interest is the regular occurrence of herbs of the family *Caryophyllaceae* (*Silene*, *Dianthus*, *Lychnis*, *Moehringia*, *Minuartia*, *Cerastium*) as well as some representatives of the family *Brassicaceae* (*Thlaspi*, *Alyssum*, *Cardaminopsis*).

BRAUN-BLANQUET & TÜXEN (1943) suggested the class of *Violetea calaminariae*. ERNST (1965, 1974, 1976b), who elaborated the syntaxonomy of the Euro-Siberian plant communities of metalliferous substrata, specified the constituents of the *Violetea calaminariae*, which was subdivided into 2 orders – the West-European and Central-European *Violetalia calaminariae* and the SE-Central-European and SE-European *Halacsyetalia sendtneri* (RITTER-STUDNIČKA 1970). The *Violetea calaminariae* should encompass both the plant communities (mainly grasslands) on ultramafic soils as well as those on anthropogenic metalliferous substrata (ore-mining wastes).

In the Eastern and Southern Alps ERNST (1965, 1974, 1976b) described the *Galio anisophylli-Minuartion vernae* with two associations – the *Thlaspietum cepaeifolii* and *Violetum dubyanae*. ENGLISCH et al. (1993) argued that it was impossible to separate the *Galio-Minuartion vernae* floristically from the *Thlaspion rotundifolii* (*Thlaspietalia rotundifolii*, *Thlaspietea rotundifolii*).

The plant communities on ultramafic rocks (e.g. serpentine) from the Eastern Alps, classified by ERNST (1965, 1974) within the *Violetalia calaminariae* (*Thlaspion calaminariae*), belong, according to MUCINA & KOLBEK (1993), to the *Avenulo praeustae-Festucion pallentis* (*Festuco-Brometea*) and will not be considered in this paper.

In our paper we attempt to revise the syntaxonomy of plant communities (dominated by phanerogams) of anthropogenic habitats with metalliferous soils. These are found in the close vicinity of ore mines exploiting minerals rich in lead, zinc and, in places, copper. The ore-mine wastes are stored in the form of heaps, and their steep, scree-like slopes offer open sites for colonization.

MATERIAL AND METHODS

All published relevés relevant to the group of plant communities studied were collected and new relevés were made in the field using the standard relevé methods of the BRAUN-BLANQUET (1964) approach; the 7-grade sampling scale (r-5) was used. In total 90 phytosociological relevés were analysed. The data relevant to field sampling (localities, geographic location, authorship, altitude, topography and size of sampled plots) are included in Appendix 1. The striking difference in sample size emerging from comparisons of the

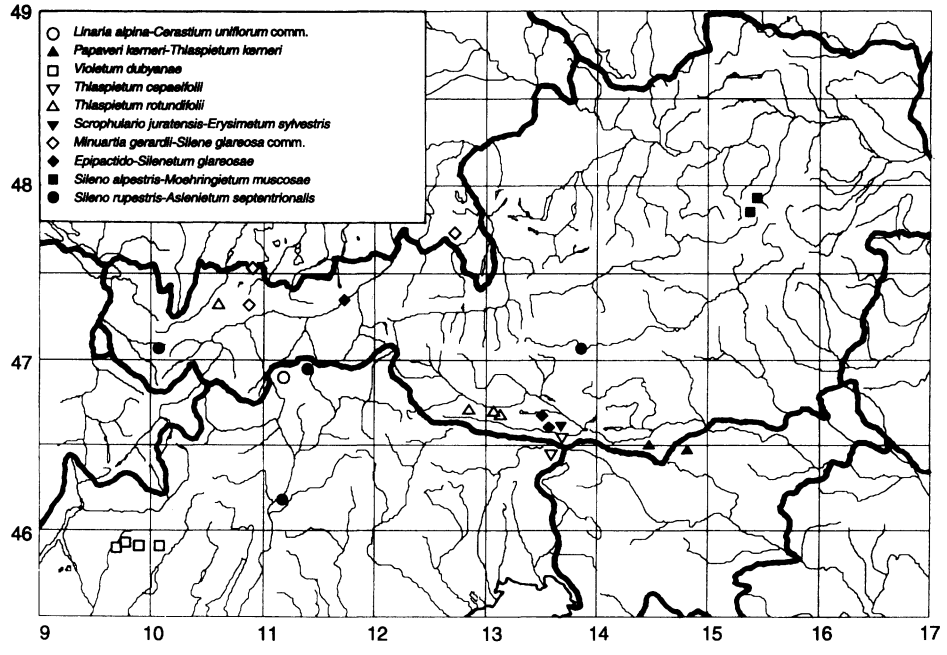

Fig. 1. Distribution of the studied group of plant communities in the Eastern Alps.

relevé data by ERNST (1974) and our unpublished relevés, did not play a role in syntaxonomic evaluations, as the number of species per plot did not vary much.

The field abundance/dominance data were transformed into the ordinal scale (0-9) of VAN DER MAAREL (1979) and classified tentatively by TWINSPAN (HILL 1979). In order to enhance the comprehensiveness of the final relevé table (Tab. 1), adjustments in the order of plant communities and diagnostic species groups were made.

Plant nomenclature for phanerogams follows EHRENDORFER (1973) and further adjustments by GUTERMANN & JUSTIN (1993). The nomenclature of mosses is according to FREY et al. (1995) and that for lichens follows TÜRK et al. (1993).

RESULTS AND DISCUSSION

Description of basic vegetation units

Ten plant communities growing on anthropogenic metalliferous soils in the Eastern Alps (Austria, Germany, Italy and Slovenia) were recognised (Tab. 1):

Linaria alpina-Cerastium uniflorum community

(Tab. 1, rels. 1-6)

This community was studied on anthropogenic spoil heaps and screes prevalent in the mining area (lead, zinc) near St. Martin am Schneeberg in the Stubaier Alps (South Tyrol). The substratum contains very high levels of heavy metals. *Silene rupestris* and *Minuartia gerardii* show expressive protoplasmatic tolerance to zinc (PUNZ et al. 1990). *Linaria alpina*,

another pioneer species colonizing these metalliferous substrata, has an exudation strategy and shows low values of tolerance. A peculiarity is the occurrence of *Juncus trifidus* on heavy-metal soils. This species was found also on copper-containing mine-spoils of the Großfragant (Hohe Tauern Mts.) in northern Carinthia (NIKLFELD, pers. comm.).

Papaveri kerneri-Thlaspietum kerneri
(Tab. 1, rels. 7-19)

This community occurs on spoil heaps around the mines in the Karawanken Mts. (ERNST 1974, PUNZ 1991). The occurrence of *Armeria alpina* in this community is remarkable. A detailed account of the community is found in ENGLISCH et al. (1993).

Violetum dubyanae
(Tab. 1, rels. 20-34)

The *Violetum dubyanae* was described by ERNST (1965, 1974) as a species-poor plant community of heavy-metal soils of the Alpi Bergamasche Mts. in northern Italy. It is characterised by the endemic *Viola dubyana*, showing protoplasmatic tolerance to heavy metals. *Minuartia gerardii* plays an important role in the community structure. *Viola dubyana* was observed to be frequent in communities on natural limestone and dolomite (metal-free) screes in the Alpi Bresciane Mts. (NIKLFELD, pers. comm.).

Thlaspietum cepaeifolii
(Tab. 1, rels. 35-38)

This very rare plant community was described from southern Carinthia by ERNST (1965, 1974). Recent floristic research (HARTL et al. 1992 and literature cited therein) shows that the original area of the community was limited only to the region of Raibl (Cave del Predil) near Tarvisio. The data on the distribution of *Thlaspi rotundifolium* subsp. *cepaeifolium* in the Karawanken and Gailtaler Alps (ERNST l.c.) are based on floristic misidentification and refer either to *T. rotundifolium* subsp. *rotundifolium* or to *Thlaspi minimum*, respectively. Endemic *Alyssum wulfenianum* is also confined to this community (NIKLFELD, pers. comm.). A short description of the community was published also by ENGLISCH et al. (1993).

Thlaspietum rotundifolii
(Tab. 1, rels. 39-45)

The *Thlaspietum rotundifolii* is one of the most widely distributed scree plant communities of the calcareous Alps (ENGLISCH et al. 1993). On anthropogenic substrata this community was found on lead-containing soils in the Gailtaler Alps in Carinthia (ERNST 1965, 1974) and in the Tegestal Valley in the North Tyrolean Calcareous Alps (PUNZ, unpubl.).

***Scrophulario juratensis-Erysimetum sylvestris* ass. nova hoc loco**
(Tab. 1, rels. 46-50; nomenclatural type: Tab. 1, rel. 46)

This is a new association described on the basis of relevés from the surroundings of Bleiberg in the Gailtaler Alps. This unit is identical to a thermophilous subassociation *erysimetosum* described by ERNST (1974: 81) within the *Thlaspietum "cepaeifolii"* (in the area only *T. rotundifolium subsp. rotundifolium* was found; HARTL et al. 1992).

***Minuartia gerardii-Silene glareosa* community**
(Tab. 1, rels. 51-55)

This community has only two small areas of distribution, namely in the Nord Tyrolean Calcareous Alps and in the Salzburg Calcareous Alps (ERNST 1965, 1974). Here it is found on mining spoils or natural scree habitats rich in heavy-metals (see also ENGLISCH et al. 1993: 291).

***Epipactido atrorubentis-Silenetum glareosae* ass. nova hoc loco**
(Tab. 1, rel.s 56-70; nomenclatural type: Tab. 1, rel. 60)

The *Epipactido-Silenetum* is a new association with a wide distribution in the Eastern Alps, in particular in the Gailtaler Alps (Carinthia) and Tuxer Alps (Tyrol). Spoils near copper and lead mines are the typical anthropogenic substratum supporting the stands of this community. *Silene vulgaris* subsp. *glareosa* is the leading species of the community. *Epipactis atrorubens* is the differential species. Species such as *Asplenium viride, Campanula cochleariifolia, Sedum album* and often rejuvenating *Picea abies, Larix decidua* and *Acer pseudoplatanus* stress the floristic similarity of the *Epipactido-Silenetum* to the *Sileno alpestris-Moehringietum* (see below). Both communities are classified within the *Petasition paradoxi.*

***Sileno alpestris-Moehringietum muscosae* ass. nova hoc loco**
(Tab. 1, rels. 71-82; nomenclatural type: Tab. 1, rel. 76)

The *Sileno alpestris-Moehringietum* is limited to heavy-metal containing natural screes of Wetterstein limestone as well as mining spoils near silver and lead mines, and has also been found in the vicinity of Mariazell (N Styria). The substratum has a high zinc and lead status (PUNZ, unpubl. data). The name-giving species are the dominants of this community; in places rich in fine, water-holding soil *Cardaminopsis halleri* becomes prominent.

Sileno rupestris-Asplenietum septentrionalis
(Tab. 1, rels. 83-90)

The stands of this community populate habitats typical of the *Thlaspietea rotundifolii* (screes and mining spoils). However, based on the floristic composition the community undoubtedly belongs to the *Asplenietea trichomanis*. The *Sileno-Asplenietum* is known from mining areas on schists (German: Glimmerschiefer) and quartzporphyr. *Silene rupestris* shows a high protoplasmatic resistence (PUNZ & ENGENHART 1990). Further information on the floristic composition and ecology of the *Sileno rupestris-Asplenietum* was summarised by MUCINA (1993: 264).

Table 1. Synoptic relevé table of the plant communities of anthropogenic habitats rich in heavy-metals in the Eastern Alps. The cover/abundance values are given in transformed form (according to VAN DER MAAREL 1979). The sign * between generic and specific names means that the name of the subspecies was given instead of the species. Abbreviations following the names of taxa: First letter – C: character-species, D – differential species (towards all other communities within the alliance), d – differential species of limited validity (only towards some of the communities within the alliance); Second letter – the community:

A: *Linaria alpina-Cerastium uniflorum* comm. (*Androsacion alpinae, Thlaspietea*); B: *Papaveri kerneri-Thlaspietum kerneri* (*Thlaspion, Thlaspietea*); C: *Violetum dubyanae* (*Thlaspion, Thlaspietea*); D: *Thlaspietum cepaeifolii* (*Thlaspion, Thlaspietea*); E: *Thlaspietum rotundifolii* (*Thlaspion, Thlaspietea*); F: *Scrophulario juratensis-Erysimetum sylvestris* (*Thlaspion, Thlaspietea*); G: *Minuartia gerardii-Silene glareosa* comm. (*Thlaspion, Thlaspietea*); H: *Epipactido atrorubentis-Silenetum glareosae* (*Petasition paradoxi, Thlaspietea*); I: *Sileno alpestris-Moehringietum muscosae* (*Petasition paradoxi, Thlaspietea*); J: *Sileno rupestris-Asplenietum septentrionalis* (*Asplenion septentrionalis, Asplenietea*).

		A	B	C	D	E	F	G	H	I	J
			1111111111	222222222233333	3333	3444444	44445	55555	555566666666667	777777777888	88888889
		123456	7890123456789	012345678901234	5678	9012345	67890	12345	678901234567890	123456789012	34567890
Cerastium uniflorum	CA	.23243	.....	.....	....	.....	.....	.....	.....	.....	.....
Saxifraga oppositifolia		.42.22	.....	.....	....	.....	.....	.....	.....	.....	.....
Juncus trifidus		.23...	.....	.....	....	.....	.....	.....	.....	.....	.....
Stereocaulon alpinum		.22.33	.....	.....	....	.....	.....	.....	.....	.....	.....2.
Thlaspi minimum	CB	.....	12212323344..	.....	....	.....	.....	.....	.....	.....	.....
Scrophularia juratensis	dB	.....	.242111.332.1	.....	....	.....	2322.	.....	3.1.....1	.....	.....
Armeria alpina	DB	.....	...332.....22	.....	....	.....	.....	.....	.....	.....	.....
Biscutella laevigata	DB	.....	..23222.....3	.....	....	.....	.....	.....	.....	.....	.....
*Cerastium * strictum*	DB	.....	...3.33.....2	.....	....	.....	.....	.....	.....	.....	.....
Polygala alpestris	DB	.....	...22.....2	.....	....	.....	.....	.....	.....	.....	.....
Cetraria islandica	DB	.....	.2343.....11	.....	....	.....	.....	.....	.....	.....	.....
Pedicularis verticillata	DB	.....	...22.....2	.....	....	.....	.....	.....	.....	.....	.....
Viola dubyana	CC	.....	.....	443332353323232	....	.....	.....	.....	.....	.....	.....
Euphrasia salisburgensis	DC	.....	.....	44544322232523.	....	.....	.....	.....	.....	....1.....	.....
Festuca ovina agg.	DC	.....	.....	.2343432242...2	....	.....	.....	.....	.....	.....	.....
Solidago virgaurea	DC	.....	.....	.....222....2.2	....	.....	.....	.....	....2.....	.....	.....
Cephaloziella starkei	dC	.....	.....	2.2..2.2.22..22	..22	...3...	.....	.....	.....	.....	.....
*Thlaspi * cepaeifolium*	CD	.....	.....	.....	5422	.....	.....	.....	.....	.....	.....
*Thlaspi * rotundifolium*	CE	.....	.....	.....	....	2243343	.....	.....	.....	.....	.....
Erysimum sylvestre	CF	.....	.....	.....	....	.....	33233	.....	...3.....	.....	.....
Racomitrium canescens	DF	.....	.....	.....	....	.....	2.53.	.....	.....	.....	.....
Epipactis atropurpurea	DH	.....	.....	.....	....	.....	.....	.....	...12...2..2...	....1.....	.....
Other species; * species with coenological valency to the *Thlaspietea rotundifolii*											
Minuartia gerardii	*	.23333	.533333555542	343323352543545	2453	434441.	44445	35532	.....1...	.....	.....
Galium anisophyllon		.....	.3.2.2...2.12	2.2332222233232	..2.	2332...	..222	2.2.2	...2.....	11	.....
*Thymus * polytrichus*		.....	.33322.222..3	333433333242433	....	..2.2..	...22	52222	.....	11	.....
Poa alpina		.....	.3332322232.3	3243552424.5.4.	2323	423222.	2..32	3...2	.....	.2212.....	.....
Linaria alpina	*	433434	222.1.2.....	.....	....	.....	.....	.....	.....444.....	.....	.....1..
Cardaminopsis halleri	*	.....	..1.....	52343	....	.....	.....	...2.	.....	...4.111....	.....
Anthyllis vulneraria		.....	...2.1.....23	.....2..2..	....	.....	.....	.....	.....	.....	.....

Tortella tortuosa		21	.......2.....	2.2.232.2232.22	.22.	...5...	.....	.....	.....	..2.....	.....
Dianthus sylvestris	*	.....	.......2..2..	...2.2.22.....	.2.2	.23.2..	.34.2	22...	.....	.....	.....
Bryum caespiticium		.....	........242..	..32..2.....	....	.....	.3...	.4...	.....	.....	.....
Cladonia pyxidata		.....	.......3.....	..3..22.2.....	....	...32..	...2.	.2352	.....	.....	.....
Molinia caerulea		.....	.....	.....	..25	.....	.....	...5.	.....	.....	.....
*Silene * glareosa*	*	.....	.......45342.	4..4454234.444.	3335	5354333	44454	43234	334344444441343	.....	...23.3.
Cardamine resedifolia	*	2	.....	.....	....	.....	.....	.....	.....	.....	.....1.2

Differential species of the *Petasition paradoxi* (comm. H & I); # – species with valency to the *Asplenietea trichomanis*

Asplenium viride	#	.....	.....	.....	....	1	.....	.....	....21.2.3.2411	12..122.33..	...2.2.2
Picea abies juv.		.....	.....	.....	....	.....	.....	.....	..2...1...23.1.	.2.22.....	.2...2..
Larix decidua juv.		.....	.....	.....	....	.....	.....	.....	.....22...12..	....1.....	.....2..
Silene nutans		.....	.....	.....	....	.....	.....	.....	..32.....2	.....	11.....
Betula pendula juv.		.....	.....	.....	....	.....	.....	.....	.....3...	.....	.22..2..
Sedum album		.....	.....	.....	....	.....	.....	.....	...2.....	33	.....
Campanula cochleariifolia	*#	.....	.....	.....	....	.....	.....	.....	....1.....	22	.....
Hieracium sylvaticum		.....	.....	.....	....	.....	.....	.....	....2.....2...	.....1...	.....
Acer pseudoplatanus juv.		.....	.....	.....	....	.....	.....	.....	.....2...	.2.1.....	.....
Silene alpestris	CI	.....	.....	.....	....	.....	.....	.....	.....	32245444	.....
Moehringia muscosa	DI#	.....	.....	.....	....	.....	.....	.....	..11.....1.33	233134322222	.....
Geranium robertianum	DI	.....	.....	.....	....	.....	.....	.....	.....	23..13222222	.....
Arabis alpina	DI*	.....	.....	.....	....	.....	.....	.....	.....	3322211.....	.....
Kernera saxatilis	DI#	.....	.....	.....	....	.....	.....	.....	.....3....	.2.23..1....	.....
Cystopteris fragilis	DI#	.....	.....	.....	....	.....	.....	.....	.....	22.11.....	.....

Species common to communities I & J

Avenella flexuosa		.....	.....	.....	....	.....	.....	.....	.....	.....2...	...221..
Mycelis muralis		.....	.....	.....	....	.....	.....	.....	.....	22.....	1.....
Silene rupestris	CJ#	1.....	.....	.....	....	.....	.....	.....	.....	.....	44332333
Asplenium septentrionale	#	.....	.....	.....	....	.....	.....	.....	.....	.....	22233..4
Anthoxanthum odoratum		.....	.....	.....	....	.....	.....	.....	.....	.....	....333.

Species with 1 or 2 occurrences in the table:

Community A: *Euphrasia* sp. relevé/value 4; B: *Campanula scheuchzeri* 19/2; *Carex firma* 8/4, 9/3; *Carex ornithopoda* 11/2, 19/2; *Hieracium* sp. 19/2; *Ranunculus montanus* 9/2, 19/2; *Tortella* sp. 8/2, 9/5; E: *Pritzelago alpina* 44/4, 45/3; G: *Cladonia alpestris* 53/3; *Cladonia verticillata* 53/3, 55/3; H: *Asplenium ruta-muraria* 60/2, 65/1; *Euphrasia rostkoviana* 62/3; *Hieracium staticifolium* 64/1, 66/4; *Polygala chamaebuxus* 66/3; *Reseda lutea* 57/1, 59/2; *Rumex* sp. 64/2, 65/2; *Salix appendiculata* juv. 62/2, 68/1; *Salix purpurea* juv. 57/2, 67/3; *Salix* sp. juv. 67/3; *Saponaria ocymoides* 57/4, 58/3; *Tussilago farfara* 57/2, 67/2; H & J: *Pinus sylvestris* juv. 67/3, 85/1; J: *Agrostis schraderiana* 90/4; *A. stolonifera* 83/1, 84/2; *Cladonia* sp. 85/1; *Galeopsis ladanum* 83/2, 84/2; *Poa nemoralis* 79/2, 80/2; *Rhizocarpon geographicum* 85/1; *Thlaspi caerulescens* 83/2, 84/3; B & H: *Acinos alpinus* 10/2, 59/2; *Silene pusilla* 19/2, 67/2.

Syntaxonomic discussion

ERNST (1965, 1974, 1976b, 1990) classified the plant communities occurring on metalliferous substrata of the Alps within the *Galio anisophylli-Minuartion vernae* (*Violetalia calaminariae*, *Violetea calaminariae*). ERNST (l.c.) has suggested *Minuartia verna* and *Silene cucubalus* (recte: *Silene vulgaris*) as the character-species of the *Violetea calaminariae*. The differential-species such as *Agrostis tenuis* and *Festuca ovina* served ERNST (l.c.) to delimit the order of *Violetalia calaminariae*, and the *Galio-Minuartion* was singled out on the basis of differential species such as *Poa alpina*, *Galium anisophyllon* and *Dianthus sylvestris*.

All of the above-mentioned species are found within a broad range of habitats and plant communities. *Poa alpina* is found in numerous grasslands and other vegetation types in the subalpine and alpine regions of the Alps, ranging from the *Molinio-Arrhenatheretea* (*Poo-Trisetetalia*) to *Elyno-Seslerietea*, *Mulgedio-Aconitetea* and *Thlaspietea rotundifolii*. *Galium anisophyllon* is found frequently in open-canopy calcareous grasslands of the *Elyno-Seslerietea* as well as in *Thlaspietea rotundifolii* communities. *Dianthus sylvestris* is typical of the inner-alpine dry grasslands (*Festuco-Brometea*) and of rocky steppes and rock-fissure communities (*Asplenietea trichomanis*). *Agrostis tenuis* (recte: *A. capillaris*) is very abundant in almost all types of nutrient-poor grasslands of the *Calluno-Ulicetea*, and partly in the *Festuco-Brometea* and *Koelerio-Corynephoretea*. It is questionable whether *Festuca ovina* as cited by ERNST (1965, 1974, 1976b) is meant in a narrow sense or as an aggregate species (as sensu EHRENDORFER 1973).

Analysis of the coenological validity of the presumed character-species of the *Violetea calaminariae* (as listed by ERNST 1965, 1974, 1976b) and the prominent presence of the species of the *Thlaspietea rotundifolii* in most of the studied communities (Tab. 1) do not support the concept of the *Violetea calaminariae* in the Alps. One of the units – the *Sileno alpestris-Asplenietum* – was classified within the *Asplenion septentrionalis, Asplenietea trichomanis*. All other studied plant communities belong to the *Thlaspietea rotundifolii*.

Syntaxonomic scheme of the studied plant communities

Thlaspietea rotundifolii BR.-BL. 1948
Androsacetalia alpinae BR.-BL. in BR.-BL. et JENNY 1926
Androsacion alpinae BR.-BL. in BR.-BL. et JENNY 1926
Linaria alpina-Cerastium uniflorum comm.
Thlaspietalia rotundifolii BR.-BL. in BR.-BL. et JENNY 1926
Thlaspion rotundifolii JENNY-LIPS 1930
Papaveri kerneri-Thlaspietum kerneri WRABER 1970
Violetum dubyanae ERNST 1965
Thlaspietum cepaeifolii ERNST 1965
Thlaspietum rotundifolii JENNY-LIPS 1930
Scrophulario juratensis-Erysimetum sylvestris PUNZ et MUCINA 1997
Minuartia gerardii-Silene glareosa comm.
Petasition paradoxi ZOLLITSCH ex LIPPERT 1966
Epipactido atrorubentis-Silenetum glareosae PUNZ et MUCINA 1997
Sileno alpestris-Moehringietum muscosae PUNZ et MUCINA 1997

Asplenietea trichomanis (BR.-BL. in MEIER et BR.-BL. 1934) OBERDORFER 1977
Androsacetalia vandellii BR.-BL. in MEIER et BR.-BL. 1934 corr. BR.-BL. et al. 1952
Asplenion septentrionalis OBERDORFER 1938
Sileno rupestris-Asplenietum septentrionalis OBERDORFER 1957

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APPENDIX

Data on localities and authorship of relevés summarized in Tab. 1. The coordinates 4654x1111 read 46°54'N and 11°11'E. IT: Italy, AT: Austria, SLO: Slovenia, DE: Germany.

No.	Country	Mountain range: Locality	Coordinates	Source
A: *Linaria alpina-Cerastium uniflorum* comm.				
01	IT	Stubaier Alpen: Schneeberg	4654x1111	PUNZ & WIESHOFER (unpubl.)
02	IT	Stubaier Alpen: Schneeberg	4654x1111	PUNZ et al. (1990)
03	IT	Stubaier Alpen: Schneeberg	4654x1111	PUNZ & WIESHOFER (unpubl.)
04	IT	Stubaier Alpen: Schneeberg	4654x1111	PUNZ et al. (1990)
05-06	IT	Stubaier Alpen: Schneeberg	4654x1111	PUNZ & WIESHOFER (unpubl.)
B: *Papaveri kerneri-Thlaspietum kerneri*				
07-13	AT	Karawanken: Hochobir	4630x1429	PUNZ (unpubl.)
14-15	SLO	Karavanke: Črna	4628x1449	ERNST (1974)
16	SLO	Karavanke: Terče	4628x1447	ERNST (1974)
17	SLO	Karavanke: Pečnik-Peca	4628x1449	ERNST (1974)
18-19	AT	Karawanken: Hochobir	4630x1429	PUNZ (unpubl.)
C: *Violetum dubyanae*				
20	IT	Alpi Bergamasche: Cima di Grem	4555x0950	ERNST (1965,1974)
21	IT	Alpi Bergamasche: Cima di Menna	4556x0947	ERNST (1965,1974)
22-23	IT	Alpi Bergamasche: Pizzo Arera	4556x0948	ERNST (1965,1974)
24	IT	Alpi Bergamasche: Monte Castello	4554x0942	ERNST (1965,1974)
25	IT	Alpi Bergamasche: Pizzo Arera	4556x0948	ERNST (1965,1974)
26	IT	Alpi Bergamasche: Presolana	4555x1005	ERNST (1974)
27	IT	Alpi Bergamasche: Monte Castello	4554x0942	ERNST (1965,1974)
28	IT	Alpi Bergamasche: Cima di Grem	4555x0950	ERNST (1965,1974)
29	IT	Alpi Bergamasche: Monte Golla	4556x0949	ERNST (1974)
30-31	IT	Alpi Bergamasche: Pizzo Arera	4556x0948	ERNST (1965,1974)
32	IT	Alpi Bergamasche: Cima di Grem	4555x0950	ERNST (1965,1974)
33	IT	Alpi Bergamasche: Monte Castello	4554x0942	ERNST (1965,1974)
34	IT	Alpi Bergamasche: Monte Secco	4555x0954	ERNST (1974)
D: *Thlaspietum cepaeifolii*				
35	AT	Gailtaler Alpen: Arnoldstein	4633x1341	ERNST (1965,1974)
36	IT	Alpi Giulie: Cave del Predil	4627x1335	ERNST (1965,1974)
37-38	AT	Gailtaler Alpen: Arnoldstein	4633x1341	ERNST (1965,1974)
E: *Thlaspietum rotundifolii*				
39	AT	Gailtaler Alpen: Reisskofel	4641x1308	ERNST (1965,1974)
40-41	AT	Gailtaler Alpen: Jauken	4642x1304	ERNST (1965,1974)
42	AT	Gailtaler Alpen: Lumkofel	4643x1251	ERNST (1965,1974)
43	AT	Gailtaler Alpen: Jauken	4642x1304	ERNST (1965,1974)
44-45	AT	Nordtiroler Kalkalpen: Tegestal	4719x1044	PUNZ (unpubl.)
F: *Scrophulario juratensis-Erysimetum sylvestris*				
46-50	AT	Gailtaler Alpen: Bleiberg	4637x1340	ERNST (1965,1974)
G: *Minuartia gerardii-Silene glareosa* comm.				
51-52	AT	Nordtiroler Kalkalpen: Wannig	4719x1052	ERNST (1965,1974)
53	AT	Nordtiroler Kalkalpen: Rauchberg	4719x1047	ERNST (1965,1974)
54	AT	Nordtiroler Kalkalpen: Biberwier	4732x1054	ERNST (1965,1974)
55	DE	Salzburger Kalkalpen: Inzeller Kienberg	4744x1243	ERNST (1974)
H: *Epipactido atrorubentis-Silenetum glareosae*				
56	AT	Gailtaler Alpen: Kreuzen	4641x1335	PUNZ (unpubl.)
57	AT	Gailtaler Alpen: Bleiberg	4637x1340	PUNZ (unpubl.)
58	AT	Gailtaler Alpen: Kreuzen	4641x1335	PUNZ (unpubl.)
59	AT	Gailtaler Alpen: Bleiberg	4637x1340	PUNZ (unpubl.)
60-61	AT	Tuxer Alpen: Falkenstein	4721x1144	PUNZ & WIESHOFER (unpubl.)
62	AT	Tuxer Alpen: Ringenwechsel	4722x1147	PUNZ (unpubl.)
63-66	AT	Tuxer Alpen: Koglmoos	4721x1145	PUNZ (unpubl.)
67	AT	Gailtaler Alpen: Koflergraben	4640x1338	PUNZ (unpubl.)
68	AT	Tuxer Alpen: Ringenwechsel	4722x1147	PUNZ (unpubl.)
69-70	AT	Gailtaler Alpen: Kreuzen	4641x1335	PUNZ (unpubl.)

I: *Sileno alpestris-Moehringietum muscosae*				
71	AT	Niederösterr. Kalkalpen: Schwarzenberg	4756x1526	PUNZ (unpubl.)
72	AT	Niederösterr. Kalkalpen: Schwarzenberg	4756x1526	PUNZ & ENGENHART (unpubl.)
73	AT	Niederösterr. Kalkalpen: Galmeikogel	4751x1522	PUNZ & PUNZ (unpubl.)
74-75	AT	Niederösterr. Kalkalpen: Schwarzenberg	4756x1526	PUNZ & ENGENHART (unpubl.)
76-77	AT	Niederösterr. Kalkalpen: Galmeikogel	4751x1522	PUNZ & ENGENHART (unpubl.)
78	AT	Niederösterr. Kalkalpen: Galmeikogel	4751x1522	PUNZ & PUNZ (unpubl.)
79-82	AT	Niederösterr. Kalkalpen: Galmeikogel	4751x1522	PUNZ & ENGENHART (unpubl.)
J: *Sileno rupestris-Asplenietum septentrionalis*				
83-84	AT	Niedere Tauern: Ramingstein	4704x1351	PUNZ & ENGENHART (1990)
85	IT	Fleimstaler Alpen: Faedo	4611x1110	PUNZ (unpubl.)
86-87	AT	Niedere Tauern: Ramingstein	4704x1351	PUNZ & ENGENHART (1990)
88-89	IT	Stubaier Alpen: Pflerschtal	4657x1124	PUNZ & WIESHOFER (unpubl.)
90	AT	Verwallgruppe: Gaflunatal	4704x1004	GRABHERR (unpubl.)

Data on altitude (Alt.), exposition (Exp.), slope (* indicate the data given in %), cover of vegetation (Cover), size of area sampled (Area), and date of sampling for the relevés summarised in Tab. 1 (x stays for missing data).

No.	Alt. m	Exp.	Slope °	Cover %	Area m^2	Date
A: *Linaria alpina-Cerastium uniflorum* comm.						
01	2150	–	–	15	1	28-06-1988
02	2350	–	–	20	4	08-07-1989
03	2150	SW	15	15	1	28-06-1988
04	2150	WSW	35	20	1	08-07-1989
05	2350	S	20	15	1	28-06-1988
06	2350	S	20	15	1	28-06-1988
B: *Papaveri kerneri-Thlaspietum kerneri*						
07	1700	SSE	32	1	4	27-06-1985
08	1700	–	–	30	4	14-08-1974
09	1700	SE	10	20	4	14-08-1974
10	1700	SSE	30	50	4	27-06-1985
11	1700	SSE	30	30	4	27-06-1985
12	1700	SSE	35	20	4	27-06-1985
13	1700	SSE	35	10	4	27-06-1985
14	950	–	–	80	50	x
15	580	–	–	80	100	x
16	800	N	20	70	100	x
17	750	NE	5	80	100	x
18	1650	SSE	0-25*	56	4	01-07-1990
19	1700	SSE	15	70	4	27-06-1985
C: *Violetum dubyanae*						
20	1900	SW	5	60	100	x
21	1700	–	–	40	100	x
22	2200	S	2	80	100	x
23	2200	–	–	50	100	x
24	1300	S	20	75	100	x
25	1400	SE	5	98	100	x
26	1800	S	20	40	100	x
27	2000	S	25	70	100	x
28	1800	S	15	20	100	x
29	1500	S	5	90	70	x
30	2000	N	5	100	100	x
31	1800	S	20	95	5	x
32	1800	SE	5	50	100	x
33	1400	SE	5	80	100	x
34	1900	S	20	60	35	x
D: *Thlaspietum cepaeifolii*						
35	800	–	–	50	25	x
36	1100	–	–	40	100	x

37	800	–	–	60	100	x
38	800	–	–	90	100	x
E: *Thlaspietum rotundifolii*						
39	1900	SW	5	80	100	x
40	2100	SSE	35	50	100	x
41	1800	S	35	70	100	x
42	1900	SSE	20	80	100	x
43	2000	SE	15	30	100	x
44	1820	N	15	5-10	16	25-06-1989
45	1870	N	–	3	4	25-06-1989
F: *Scrophulario juratensis-Erysimetum sylvestris*						
46	1300	SE	35	30	100	x
47	1100	SSE	25	40	100	x
48	1000	SE	25	70	100	x
49	1200	S	25	60	100	x
50	1200	ESE	25	60	100	x
G: *Minuartia gerardii-Silene glareosa* comm.						
51	1700	SW	20	70	100	x
52	1600	W	15	80	100	x
53	1500	SW	15	60	100	x
54	1000	–	–	80	100	x
55	1220	N	5	40	35	x
H: *Epipactido atrorubentis-Silenetum glareosae*						
56	1100	S	30*	15	9	03-07-1990
57	1100	S	35	20	25	27-06-1987
58	1100	S	30*	20	4	03-07-1990
59	1200	S	30	35	25	27-06-1987
60	840	NW	35	5	9	24-06-1988
61	840	NW	35	5	4	24-06-1988
62	1140	NW	30	15	4	24-06-1989
63	1160	NW	35	10	4	24-06-1989
64	1160	NW	35	10	4	24-06-1989
65	1160	NW	35	10	4	24-06-1989
66	1160	NW	35	20	9	24-06-1989
67	900	–	–	15	100	27-06-1987
68	1140	NW	30	15-20	4	24-06-1989
69	1100	S	0-10*	50	4	03-07-1990
70	1100	S	25*	15	1	03-07-1990
I: *Sileno alpestris-Moehringietum muscosae*						
71	980	NNE	35	5	4	22-05-1990
72	980	NNE	30	15	9	22-05-1990
73	1200	-	–	40	1	11-07-1990
74	980	NNE	25	25	4	22-05-1990
75	980	NNE	35	10	4	19-09-1990
76	1200	E	30	25	4	05-08-1989
77	1200	ESE	35	25	4	05-08-1989
78	1200	ESE	35	30	4	11-07-1990
79	1200	E	30	40	4	05-08-1989
80	1200	ESE	30	40	4	05-08-1989
81	1200	S	35	15-20	4	05-08-1989
82	1200	ESE	35	20	4	05-08-1989
J: *Sileno rupestris-Asplenietum septentrionalis*						
83	1060	S	30	5	4	08-08-1988
84	1060	S	30	10	4	08-08-1988
85	850	NNW	10	5	1	29-06-1987
86	1150	NE	35	5	4	08-08-1988
87	1150	NE	35	10	4	08-08-1988
88	1800	NNE	30	3	4	25-06-1988
89	1800	SE	30	5	4	25-06-1988
90	975	SSW	x	x	25	15-09-1982