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HEAVY MINERALS FROM URGONIAN LIMESTONE PEBBLES OF THE NORTHERN CALCAREOUS ALPS (AUSTRIA, BAVARIA): FURTHER EVIDENCE FOR AN INTRA-AUSTROALPINE SUTURE ZONE

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Abstract: Shallow-water limestones of the Lower Cretaceous occur as allochthonous detritus within several Cretaceous and Tertiary formations of the Northern Calcareous Alps (NCA). Allodapic limestones and Urgonian limestone pebbles of a presumed NCA-internal origin are characterized by heavy mineral assemblages rich in chrome spinel. Microprobe analysis indicates the predominance of chrome spinels with relatively high Cr-contents, suggesting harzburgite-bearing ophiolite sequences in the source area. A similar geochemistry is known from detrital chrome spinels observed in the deep-water clastics of the Rossfeld Formation (Upper Valanginian-Aptian), which are derived from a southern, intra-Austroalpine source. On a chrome spinel-free base significant amounts of garnet and staurolite characterize the heavy mineral associations of both, the allochthonous Urgonian limestones as well as the Rossfeld Formation. Similar chrome spinel distributions are also known from the Lower Cretaceous of northern Hungary, whereas data from detrital chrome spinels of the Western Carpathians are not comparable. Detrital chrome spinels in Urgonian limestone pebbles, therefore, represent further evidence for the existence of a Cretaceous intra-Austroalpine suture zone south of the Northern Calcareous Alps and its continuation into the Carpathian-Pannonian region.

Key words: Northern Calcareous Alps, Austria, Cretaceous, Urgonian limestone, heavy minerals, chrome spinel.

Introduction

Heavy mineral assemblages from sands and sandstones comprise a valuable tool to characterize source areas and to interpret the setting and evolution of sedimentary basins in orogenic belts (e.g. Woletz 1967; Zimmerle 1984; Morton 1985; Stattegger 1986a, b; Faupl & Wagreich 1992a). The Cretaceous of the Eastern Alps constitutes a classical example of the impact of heavy mineral studies to the interpretation of orogenic wedge evolution since the pioneer works of Woletz (1963, 1967). Heavy mineral investigations, particularly the tracing of the ophiolite-derived chrome spinels, resulted in a detailed scenario for the evolution of source areas during the Cretaceous and Tertiary of the Eastern Alps (e.g. Woletz 1967; Dietrich & Franz 1976; Wildi 1985; Winkler 1988; Faupl & Wagreich 1992a). The existence and evolution of a formerly unknown ophiolitic suture zone in the internal part of the Austroalpine unit was primarily deduced from heavy mineral associations rich in chrome spinel (e.g. Faupl & Tollmann 1979; Faupl 1983; Decker et al. 1987; Pober & Faupl 1988; Faupl & Pober 1991). This paper presents chrome spinel-rich heavy mineral assemblages from Lower Cretaceous shallow-water "Urgonian" limestones and sandy limestones of the Northern Calcareous Alps (NCA), which are considered to have been derived from this intra-Austroalpine suture zone.

The NCA are a structurally complex pile of cover nappes of the Austroalpine tectonic unit, originating from the northern part of the Adriatic plate (for a paleogeographic review see Faupl & Wagreich 1992a). Lower Cretaceous shallow-water carbonate sediments are only preserved as clasts in allodapic limestones and as pebbles within Cretaceous and Tertiary deposits of the NCA. Such detritus of Urgonian facies are known from a range of different formations (Figs. 1 and 2), e.g. the Lower Cretaceous of the Thiersee Syncline (Hagn 1982; Schlagintweit 1991a), the Losenstein- and Branderfleck Formation of the NCA (Gaupp 1980; Schlagintweit 1991b) and the Gosau Group (Weidich 1984; Schlagintweit 1987, 1991a; Wagreich & Schlagintweit 1990). Two different source areas of Lower Cretaceous platform limestones, one to the north and a second one within the NCA, were deduced on the base of the microfossil content, limestone facies types and paleogeographic setting (e.g. Weidich 1990; Schlagintweit 1991a, b).

The presence of detrital chrome spinel in Urgonian limestones of a proposed southern source was regarded as additional evidence for the existence of an ophiolitic suture zone within the Austroalpine unit, situated to the south of the NCA (e.g. Schlagintweit 1990; Faupl & Wagreich 1992a). Heavy mineral investigations on Urgonian limestone pebbles, especially the composition of detrital chrome spinel, therefore constitute an important key for the understanding of the paleogeographical and geodynamic evolution of the NCA during the Cretaceous.

Sample localities

Pebbles of Urgonian limestones are known from several localities of Cretaceous and Tertiary clastic deposits across the whole NCA (Fig. 1). Detailed microfacial descriptions of these

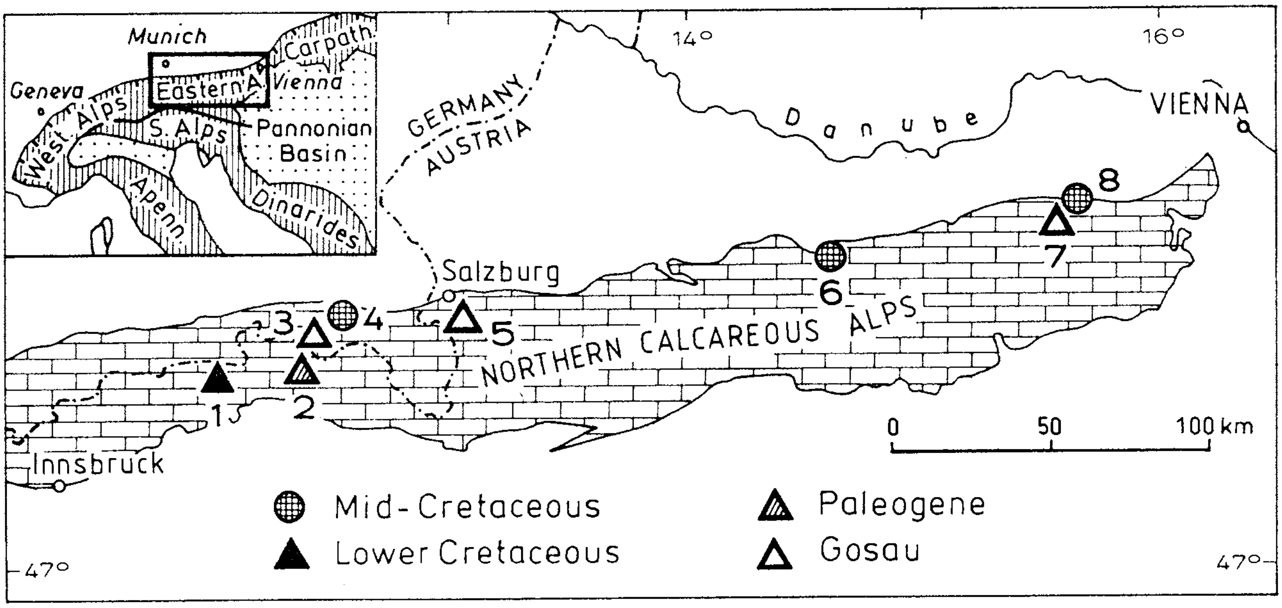

Fig. 1. Sample localities of Urgonian clasts: 1 - Thiersee Syncline (Lower Cretaceous); 2 - Kössen, Kohlenbach section of Unterinntal Tertiary (Paleogene); 3 - Oberwössen (Gosau Group); 4 - Urschlauer Achen (Branderfleck Fm.); 5 - Gaisberg (Gosau Group); 6 - Frankenfels Nappe (Losenstein Fm.); 7 - Lilienfeld (Gosau Group); 8 - Marktl (Branderfleck Fm.).

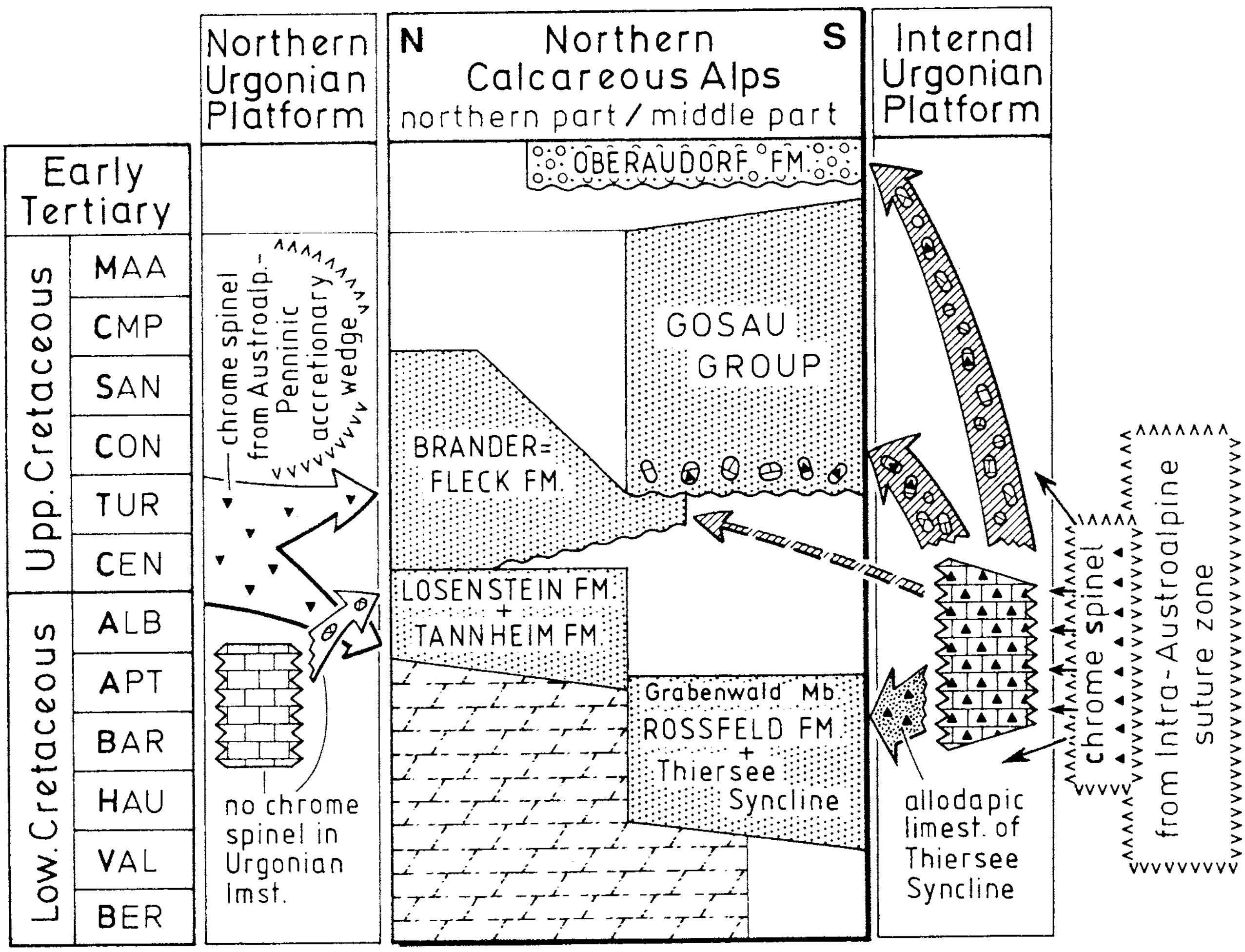

Fig. 2. Lithostratigraphy of the Cretaceous-Paleogene of the Northern Calcareous Alps. Schematic position of presumed Lower Cretaceous Urgonian-type platforms to the north and to the south; reworking is indicated by arrows.

limestones are presented by Hagn (1982) and Schlagintweit (1987, 1991a) for the western part of the NCA and by Wagreich & Schlagintweit (1990) and Schlagintweit (1991b) for the eastern part. Data about the heavy mineral content of the Urgonian limestones of the Alps are scarce. Hagn (1982) and Schlagintweit (1991a) mentioned the occurrence of chrome spinel grains in thin sections of Urgonian limestones from the western NCA, where they are often incorporated into tests of orbitolinas (Fig. 3).

From the following localities, heavy mineral associations were separated from Urgonian limestone pebbles during this study:

1 - Barremian/Aptian deposits of the Thiersee Syncline (Hagn 1982; Schlagintweit 1991a);

2 - Coniacian basal conglomerates of the Gosau Group of Kössen/Oberwössen (Schlagintweit 1987, 1991a);

3 - Upper Eocene/Oligocene conglomerates (Oberaudorf Fm.?) of the Unterinntal Tertiary Basin and the Kössen area (Kohlenbach section, Schlagintweit 1991a);

4 - Coniacian? basal conglomerates of the Gosau Group of the Gaisberg south of Salzburg (Glasenbach Gorge);

5 - Coniacian/Santonian basal conglomerates of the Gosau Group of Lilienfeld 50 km W of Vienna (Wagreich & Schlagintweit 1990).

For comparison with the autochthonous sediments of the NCA, heavy minerals were also separated from 3 localities of Albian/Cenomanian clastic deposits of the NCA and from one locality of the Late Cretaceous Gosau Group (Fig. 1):

1 - Cenomanian basal sandstones of the Branderfleck Formation with orbitolinids in the section of the Urschlauer Achen in Bajuvaria (Hagn 1981, p. 253);

2 - Cenomanian orbitolinid-bearing sandstones from Marktl near Lilienfeld (Faupl & Wagreich 1992b);

3 - Upper Albian/Lower Cenomanian sandstones of the Losenstein Formation of the eastern part of the NCA (Faupl & Wagreich 1992b);

4 - Santonian deep-water sandstones of the Gosau Group of Kössen/Oberwössen (Vogelwand section, Dietrich & Franz 1976).

Published data from Faupl & Tollmann (1979), Gaupp (1980) and Winkler (1988) on heavy mineral associations of the Rossfeld Formation (Upper Valanginian-Aptian), the Losenstein Formation (Albian-Lower Cenomanian) and the Branderfleck Formation (Cenomanian-Campanian) were also used. Additional data from the Late Cretaceous Gosau Group are included.

Methods

Heavy mineral samples were prepared from crushed limestone and sandy limestone pebbles, which were decalcified in acidic acid. Gravitational heavy mineral separation of the sieve fraction 0.4 to 0.063 mm was carried out using tetrabromethane as heavy liquid. This method gave good results, especially for limestone pebbles, in which chrome spinel grains were already found in thin sections. Heavy minerals such as canada-balsam-mounted grain concentrates were identified under the petrographic microscope and counted using the ribbon-method.

Although the total amount of heavy mineral grains was sometimes rather low due to the limited sample size of some of the smaller pebbles, 18 of 25 samples gave an interpretable amount of 100 or more translucent heavy mineral grains (Tab. 1). In some of the limestone samples, the total insoluble residue consisted of more than 90 % of chrome spinel. The non-chrome spinel fraction of the heavy mineral assemblages were separately counted and are also presented on a chrome spinel-free base (Tab. 2), examplifying the importance of trace amounts of these heavy minerals in the characterization of source areas.

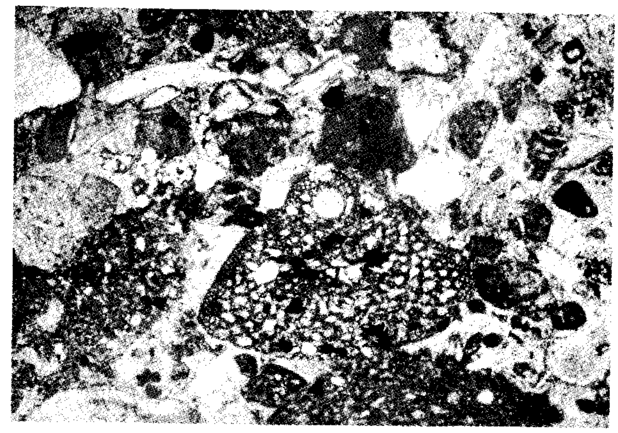

Fig. 3. Megalospheric specimen of *Palorbitolina lenticularis* (Blumenbach) with agglutinated grains of chrome spinel in the test (dark grains). Allodapic limestone, Lower Aptian, Thiersee Syncline (Magnification ca. ×15).

The chemical composition of detrital chrome spinel grains was investigated under a ARL-SEMQ microprobe (20 kV acceleration potential). Preparation methods of samples and processing of data have been described in detail by Pober & Faupl (1988) and references have been given therein.

Heavy mineral data from Urgonian limestone pebbles

Heavy mineral associations of Urgonian limestone pebbles (Tab. 1) are dominated by high amounts of chrome spinel. Extremely high contents of chrome spinel characterize the Upper Barremian to Lower Aptian allodapic limestones of the Thiersee Syncline (about 98 %). Slightly younger Urgonian limestone pebbles from the basal conglomerates of the Kössen/Oberwössen Gosau Group (94-77 %) and the Gosau Group of Lilienfeld (66-99 %) are also rich in chrome spinel. In these cases, the heavy mineral content as well as the striking microfacies similarities (Wagreich & Schlagintweit 1990) point to a comparable source area for the Urgonian limestone pebbles from both the western and the eastern parts of the NCA. Otherwise, pebbles of the Paleogene Kohlenbach section (Tertiary of the Unterinntal) and pebbles from Cenomanian calcareous sandstones wihin the the Kössen/Oberwössen Gosau Group show conspicuous by lower amounts of chrome spinel (21-29 %), probably due to different paleogeographical settings in relation to terrigenous sources (Schlagintweit 1991a).

Two samples from Urgonian limestones of the Lilienfeld Gosau Group show a heavy mineral association without chrome spinel, but with high amounts of tourmaline, staurolite, zircon, and rutile. The high percentages of staurolite (25-48 %) accompanied by low amounts of garnet (1-2 %) are an outstanding feature.

The most significant trend in the heavy mineral distribution, calculated on a chrome spinel-free base (Tab. 2), is the consistent amount of garnet (11-48 %) and staurolite (2-10 %) besides zircon (14-42 %), tourmaline (4-49 %), rutile (4-13 %) and apatite (1-22 %). Traces of blue amphiboles were only found in two Urgonian limestone pebbles: Hi67 of Albian age

Table 1: Heavy mineral data from Urgonian limestones and related formations (frequency percents are based on grain counts; size range 0.4-0.063 mm; + = below 0.5 %).

	ZIR	TUR	RUT	APA	GAR	CHL	STA	EPI	CHR	AMP	SON	N
Allodapic limestones (Barremian-Aptian) of the Thiersee Syncline												
GB5	+	1	+	+	+	0	+	0	97	0	+	(308)
GB20	1	+	+	+	1	0	+	0	98	0	+	(307)
GB21	1	+	+	+	1	0	+	0	98	0	+	(306)
GB22	1	+	+	+	+	0	+	0	98	0	0	(305)
EJK44	+	+	+	1	+	0	+	0	98	0	0	(307)
Urgonian pebbles (Aptian-Albian) from the Kössen/Oberwössen Gosau Group												
L120	4	1	1	+	2	0	+	0	90	0	+	(388)
L120B	3	11	2	3	3	0	+	0	77	0	0	(333)
L123	1	1	1	+	2	0	0	0	94	0	0	(319)
Hi6	1	1	1	2	2	0	1	0	92	0	0	(325)
Hi11	3	2	1	2	5	0	+	0	86	0	+	(349)
Hi67	3	2	1	1	3	0	+	0	88	0	+	(340)
Urgonian pebble (Aptian-Albian) from the Paleogene Kohlenbach section												
K1b	15	13	3	5	36	+	5	2	21	0	0	(288)
Cenomanian sandstone pebbles from the Kössen/Oberwössen Gosau Group												
Kö1	15	28	6	11	5	0	1	0	29	1	2	(308)
Kö2	30	21	10	3	6	0	1	0	27	1	+	(405)
Cenomanian? pebble from the Gosau Group of the Gaisberg (Salzburg)												
Glas1	1	1	1	1	2	0	0	0	94	0	0	(272)
Urgonian pebbles (Aptian) from the Gosau Group of Lilienfeld												
LIu1	0	+	+	+	0	0	0	0	99	0	0	(253)
LIu12	9	4	2	4	3	0	+	0	77	+	0	(277)
LIu27	10	8	5	7	3	0	0	0	66	0	0	(250)
LIu230	10	34	6	0	2	0	48	0	0	0	0	(268)
LIu232	22	45	7	0	1	0	25	0	+	0	0	(333)
Branderfleck Formation of Urschlauer Achen (Cenomanian)												
UA1	3	4	+	1	2	1	+	0	87	1	0	(309)
UA2	3	2	1	1	3	1	+	0	88	+	+	(261)

Abbreviations: ZIR - zircon, TUR - tourmaline, RUT - rutile, APA - apatite, GAR - garnet, CHL - chloritoid, STA - staurolite, EPI - epidote/clinozoisite/zoisite, CHR - chrome spinel, AMP - blue alkali amphibole, SON - other minerals (hornblende, cyanite, ...). N - number of translucent heavy mineral grains counted

(Gosau Group of Kössen/Oberwössen), LIu12 of Aptian age (Gosau Group of Lilienfeld).

Composition of the detrital chrome spinels

Electron microprobe analysis was performed on detrital chrome spinels from Urgonian limestone pebbles sampled from the basal conglomerate of the Gosau Group of Kössen/Oberwössen (samples Hi6, Hi11, Hi67, L120; comp. Schlagintweit 1987) and from an Upper Barremian allodapic limestone with shallow-water detritus of the Thiersee Syncline (GB20). The data are presented in diagrams of Cr# (= Cr/[Cr+Al]) versus Mg# (= Mg/[Mg+Fe^{2+}]).

On the basis of 75 analyse of chrome spinel grains from Urgonian limestone pebbles (Fig. 4a), the majority plot into the harzburgite field and only less than 10 % in the field of podiform chromites (see Pober & Faupl 1988: Fig. 1b). Metamorphic influences can be excluded in comparison with data given by Evans & Frost (1975). Metamorphic spinels of low to medium metamorphic grades are characterized by a distinct decrease in Mg# comprising all the Cr#-range. Al-rich chrome spinels with Cr# below 0.4 characteristic for lherzolitic source rocks are totally missing.

In general, the composition of the chrome spinels of the Urgonian limestone pebbles indicates erosion of ultramafic ophiolitic bodies in the source terraines. According to the petrogenic classification of Dick & Bullen (1984), the chrome spinels suggest a derivation from type III peridotites. The majority of the spinels plot at the Fe-rich margin of the type III-peridotite field (see Pober & Faupl 1988: Fig. 1c), only about 15 % are ascribed to the field of type I-peridotites.

According to Dick & Bullen (1984) type III-peridotites are characterized by spinel Cr# substantially above 0.6. Their formation is related to initial magmatic arc development. Lherzoli-

Table 2: Heavy mineral data calculated on a chrome spinel-free base from Urgonian limestones and related formations (only samples with more than 100 non-chrome spinel grains were considered. For abbreviations see Table 1).

	ZIR	TUR	RUT	APA	GAR	CHL	STA	EPI	AMP	SON	N
Allodapic limestones (Barremian-Aptian) of the Thiersee Syncline											
GB5	14	31	12	9	23	0	2	0	0	9	(105)
GB20	29	4	4	5	48	0	7	0	0	3	(115)
GB21	34	15	14	3	28	0	5	0	0	1	(113)
GB22	43	9	4	9	25	0	9	0	0	0	(103)
Urgonian pebbles (Aptian-Albian) from the Kössen/Oberwössen Gosau Group											
L120	45	15	11	1	25	0	2	0	0	1	(109)
L120B	16	49	7	12	14	0	3	0	0	0	(103)
Hi6	14	18	10	22	26	0	10	0	0	0	(100)
Hi11	25	15	5	17	34	0	4	0	0	+	(162)
Hi67	26	21	10	11	28	0	4	0	1	1	(105)
Urgonian pebble (Aptian-Albian) from the Paleogene Kohlenbach section											
Klb	19	16	4	7	45	+	7	2	0	0	(228)
Cenomanian sandstone pebbles from the Kössen/Oberwössen Gosau Group											
Kö1	22	40	8	16	7	0	2	1	2	2	(218)
Kö2	41	28	13	4	9	0	2	+	2	+	(295)
Urgonian pebble (Aptian) from the Gosau Group of Lilienfeld											
LIu12	42	16	8	19	11	0	2	0	2	0	(102)
Branderfleck Formation of Urschlauer Achen (Cenomanian)											
UA1	24	30	2	7	19	12	1	0	5	0	(110)
UA2	29	17	10	12	23	6	1	0	2	+	(154)

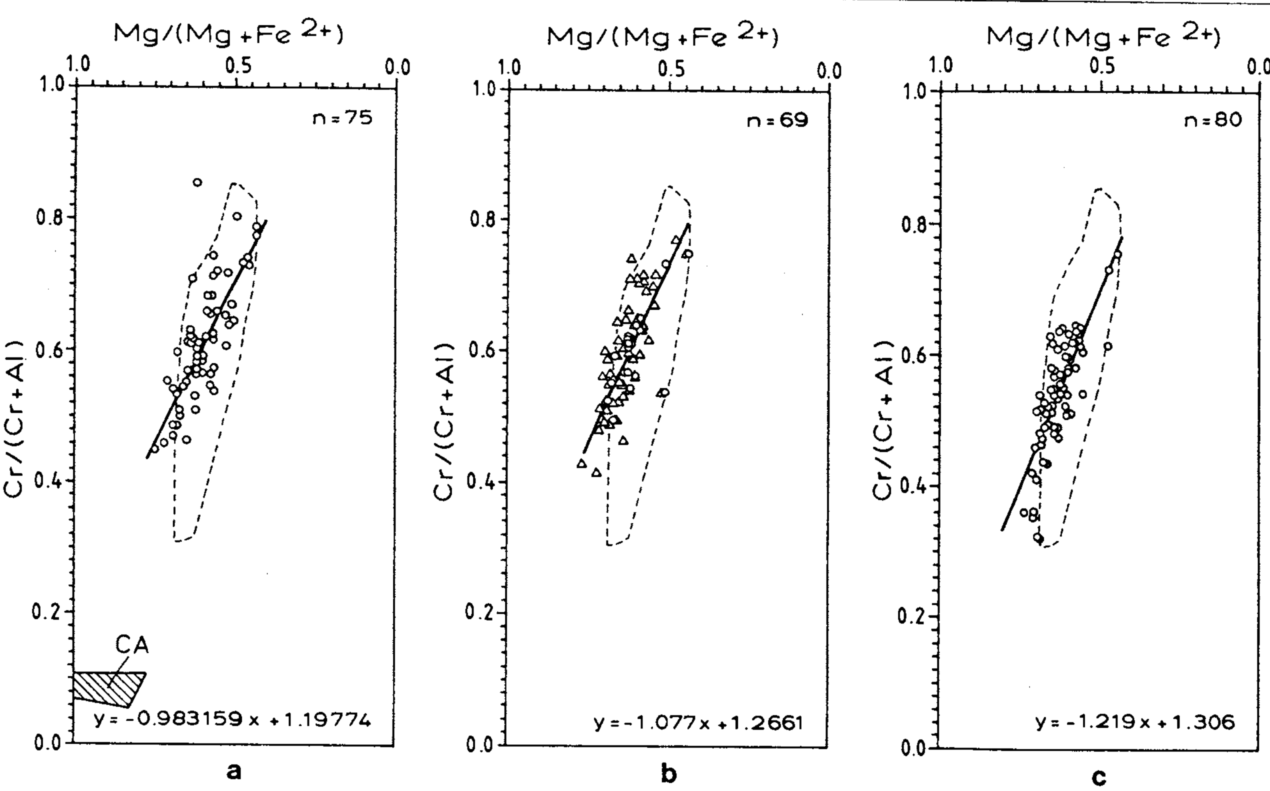

Fig. 4. Spinel compositions from **(a)** Urgonian limestone pebbles from the Kössen/Oberwössen Gosau Group (samples Hi6, Hi11, Hi67, L120) and **(b)** allodapic limestones of the Thiersee Syncline (circles - sample GB20, triangles - data from Pober & Faupl 1988). **(c)** Santonian sandstones of the Kössen/Oberwössen Gosau Group. n - number of chrome spinel grains measured, Y - regression equation. CA in Fig. 4a depicts compositional field of spinels from Urgonian limestones pebbles of the Pieniny Klippen Belt of the Western Carpathians (Mišík et al. 1980). Dashed line indicates harzburgite field (Pobes & Faupl 1988).

tic rocks are quite rare in such ophiolitic complexes. On the contrary, spinel Cr# of type I-peridotites does not exceed 0.6 and these chrome spinels are considered to have been formed in a mid-ocean ridge setting. The ultramafics of this setting are rich in lherzolitic rocks but harzburgites are not excluded. Type II-peridotites represent ophiolites with a more transitional spinel Cr# range. Such complexes are thought to have been developed under multiphase melting conditions.

The composition of chrome spinels from allodapic limestones of the Thiersee Syncline (Fig. 4b) are highly comparable with those from the Urgonian pebbles. Their Cr# values are also above 0.4, but the center of their distribution is slightly shifted to the Fe-rich side. Compared to the data from the Rossfeld Formation of the middle and eastern part of the NCA (Pober & Faupl 1988: Fig. 5; Faupl & Pober 1991: Fig. 1) and the Lavant Formation of the Drau Range near Lienz (Pober & Faupl 1988: Fig. 10a; Faupl & Pober 1991: Fig. 4), their conformity with the chrome spinel distributions of the Urgonian limestone pebbles and allodapic limestones is highly remarkable. Therefore, we believe that the ophiolitic source was the same.

The composition of the chrome spinels from the Urgonian limestone pebbles differs markedly from data of the sandstones of the Losenstein Formation (Pober & Faupl 1988: Fig. 6a), the Branderfleck Formation (Pober & Faupl 1988: Fig. 6b) and the Turonian-Santonian sandstones of the Gosau Group of Brandenberg (Pober & Faupl 1988: Fig. 8a) as well as from our new data from the Vogelwand section of the Kössen/Oberwössen Gosau Group (Fig. 4c). The chrome spinel compositions from these formations are characterized by the presence of Al-rich spinels and also some Cr-rich ones not recognized in the samples of the Urgonian limestones. These differences can be demonstrated particularly by comparing the detrital chrome spinel distributions from Urgonian limestone pebbles of the Kössen-Oberwössen Gosau (Fig. 4a) and of the Santonian sandstones of the same locality (Fig. 4c), examplifying the change in the ophiolitic sources between the Aptian/Albian and the Late Cretaceous (Faupl & Pober 1991).

Discussion and conclusions

Two source areas including ophiolitic remnants and Lower Cretaceous shallow-water limestones were active during the Cretaceous deposition within the NCA (e.g. Decker et al. 1987; Schlagintweit 1991a; Faupl & Wagreich 1992a; comp. Fig. 2). Heavy mineral assemblages of Urgonian limestone pebbles with a suggested NCA-internal source (e.g. Thiersee Syncline and Gosau Groups of Kössen-Oberwössen and Lilienfeld; Hagn 1982; Schlagintweit 1987, 1991a; Wagreich & Schlagintweit 1990) are characterized by high chrome spinel contents up to 98 %. The recalculation of heavy minerals on a chrome spinel-free basis results in heavy mineral assemblages with a significant amount of garnet and staurolite (Fig. 5). Similar assemblages are known from clastic sediments of the Rossfeld Formation and the Grabenwald Formation of the NCA, whose southern derivation is confirmed by paleoslope data (Faupl & Tollmann 1979; Decker et al. 1987). Similar trends in the composition of the chrome spinels provide additional evidence for similar ophiolitic sources for the NCA-internal Urgonian platform as well as for the Rossfeld Formation.

Heavy mineral assemblages from formations with Urgonian limestone pebbles of a proposed northern affinity, e.g. from the Losenstein Formation at the northern margin of the NCA (Schlagintweit 1991a, b), differ essentially from those of southern provenance. Although high chrome spinel contents are also observed in the turbiditic sandstones, chloritoid and epidote are more common than garnet and staurolite (Fig. 5). Only a few samples of the Branderfleck Formation (Winkler 1988) plot into the field of the Urgonian limestone pebbles. Further evidence for a separation of these two clastic sources comes from the composition of the chrome spinels. Chrome spinel distributions from sandstones of the Losenstein Formation indicate significant differences such as a trend to higher Al-contents in comparison with chrome spinel distributions from Urgonian limestone pebbles and the Rossfeld Formation.

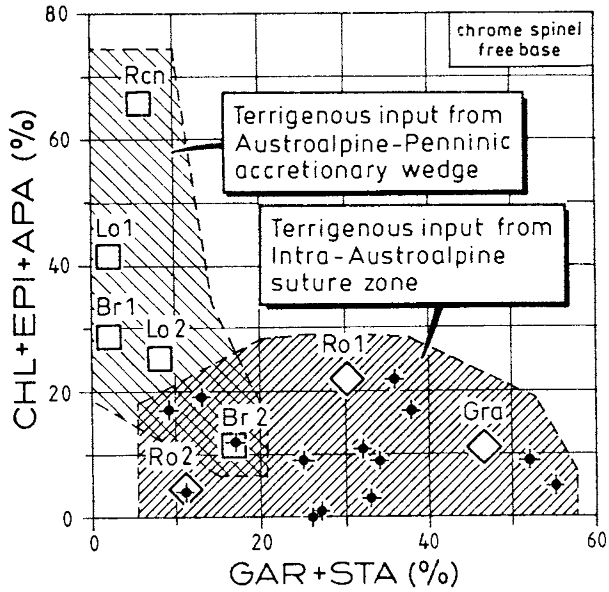

Fig. 5. Heavy mineral discrimination diagram garnet+staurolite vs. chloritoid+epidote+apatite, calculated on chrome spinel-free base. Crosses - samples from Urgonian limestones. Squares - means of samples from the following localities: **Rcn** - "Randcenoman" Weyerer Arc, Aptian/Albian (Faupl & Wagreich 1992b); **Lo1** - Losenstein Fm. Frankenfels Nappe, (Faupl & Wagreich 1992b); **Lo2** - Losenstein Fm. western NCA, (Winkler 1988); **Br1** - Branderfleck Fm. Marktl (Faupl & Wagreich 1992b); **Br2** - Branderfleck Fm. western NCA, (Winkler 1988); **Ro1** - Rossfeld Fm. Rossfeld SW Salzburg (Faupl & Tollmann 1979); **Ro2** - Rossfeld Fm. Weyerer Arc (Decker et al. 1987); **Gra** - Grabenwald Member of Rossfeld Fm. Grabenwald (Faupl & Tollmann 1979; Faupl unpubl.).

Both, the chrome spinels of the Urgonian limestone pebbles and those from the Rossfeld Formation indicate an ophiolitic source comprising mainly harzburgites. Comparable chrome spinel compositions are reported from the Lower to mid-Cretaceous of the Gerecse Mts. of northern Hungary (Árgyelán 1992), where the same type of Urgonian limestones occur as pebbles in a formation comparable to the Rossfeld Formation (Schlagintweit 1990). Otherwise, the few data on detrital chrome spinels from Mid-Cretaceous sediments and Urgonian pebbles (Mišík 1990) of the Western Carpathians (Mišík et al. 1980, 1981) show a totally outstanding composition (very high Al-content, comp Fig. 4b) unknown from the Eastern Alps. The intra-Austroalpine source terrain seems to have been built up by great amounts of type III-peridotites. These type III-peridotites are generally considered to have been formed during the development of a magmatic arc which was later obducted. The southern, intra-Austroalpine provenance area of the harzburgite-dominated ophiolithic material has been interpreted by Pober & Faupl (1988) and Faupl & Pober (1991) as remnants of a suture zone of the Tethyan realm to the south of the NCA. This suture zone may have been a continuation of ophiolite complexes of the Dinarides (Roeder 1976; Faupl & Pober 1991; Wagreich 1993), e.g. the Vardar Zone, where a harzburgite-rich ophiolite belt is known (e.g. Maksimovic & Majer 1981). Slices of ultrabasic rocks and oceanic sediments in the Meliata Zone of the Western Carpathians and the NCA (Mandl & Ondrejičková 1991; Kozur & Mostler 1992) can be interpreted as remnants of this southern oceanic realm.

To the north of this intra-Austroalpine oceanic suture zone, within the NCA, an Urgonian shallow-water platform developed during the Early Cretaceous. Chrome spinel, derived from the intra-Austroalpine suture zone, is the dominant heavy mineral in these deposits. This carbonate platform was completely eroded and remnants are only preserved as pebbles within Cretaceous and Tertiary formations of the NCA.

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