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The Hochgrössen Ultramafic Rocks and Associated Mineralizations, Rottenmann Tauern, Austria

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With 2 figures and 7 tables

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Abstract

The Hochgrössen ultramafic massif is a Palaeozoic alpine-type ultramafic body whose present characteristics are more akin to metamorphic tectonites than to igneous ultramafics. As a metamorphic tectonite its history can be deciphered by considering the interplay of deformations and the accompanying readjustments to which the massif was subjected.

The most important readjustment was a serpentinization (i. e. antigoritization) event which affected both the silicates and the associated sulphides and oxides.

Geochemical data collected from the silicates and oxides of the massif emphasize the geological and economic roles serpentinization plays by readjusting ultramafic and ultrabasic rocks.

The geological evolution of the Hochgrössen ultramafic massif is considered to have commenced with transport from the mantle. Continuing investigations are aimed at clarifying whether the mechanisms involved can be integrated into the system of plate tectonics.

Introduction and geological setting

The Hochgrössen ultramafic massif is situated within the Rottenmann Tauern and lies about 14 km Southwest of Selztal in the Province of Styria in Austria. The area under investigation is approximately 3.5 × 4.0 km in dimensions and is situated on the western side of the Gulling Valley near the village of Oppenberg.

On a regional scale, the Hochgrössen massif forms part of a series of ultramafic and ultrabasic lenticular bodies which occur over 150 km along a WNW-trending line, extending from North of Graz in the East to the Rottenmann Tauern in the West. The most extensive and best-known member of this group is the Kraubath massif. The same regional trend

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is also exhibited by the Gleinalm rocks which lie in contact with the Hochgrössen and the Kraubath massif, as illustrated by the geological map of Styria (METZ, 1957).

The eastern and northeastern margins of the Hochgrössen ultramafic massif lie in thrusted contacts with the Seckauer (Bösenstein) gneiss. Thrusted contacts are also exhibited with the Rannach serie schists on the western and northwestern borders of the massif, and with phyllitic schists on the southwestern corner of the body. The ultramafic massif is terminated to the south by the Hochgrössen gneiss-amphibolite series. The regional geology has been outlined by METZ (1964) and BACHMANN (1964) who considered the rocks surrounding the ultramafic massif to be of Palaeozoic age and by TOLLMANN (1977).

The Hochgrössen ultramafic massif is made up of serpentine-mylonites which are restricted in occurrence to thrust zones; serpentinite, occupying the central part of the massif and serpentinized dunite, occurring at the southwestern part of this body. talc-carbonates, – forming lenticular bodies – are found in the northeastern and southeastern parts of the massif, and garnet-amphibolites occur within its northern and southern parts.

Deformations and readjustments

The Hochgrössen ultramafic massif is a rootless tectonic sheet (Fig. 1) which was subjected to four deformational events. The earliest (T_1) was a thrusting event believed to have taken place during the emplacement stage of the massif. The second (T_2) was a folding event resulting in the development of anticlinal and synclinal closures. The third (T_3) was a thrusting event. It was followed by another thrusting event (T_4) which was responsible for transporting the ultramafic massif to its present-day position (Fig. 1).

Petrographic studies of the Hochgrössen ultramafic rock assemblages and its surrounding rocks carried out in the course of the present investigation indicate that textural and mineralogical readjustments have accompanied and/or followed the four deformational events. These readjustments are designated as M_1 to M_4 from older to younger respectively (Table 1).

The earliest event (T_1) resulted in intensive mylonitization due to which first generation serpentine-mylonite (M_1) was formed.

The second event (T_2) was a regional deformational as well as metamorphic event (M_2). It was accompanied by intensive serpentinization of the ultramafic massiv leading to the formation of the present-day serpentinized dunite, serpentinite and talc-carbonates. The earlier formed serpentine-mylonite was intensely recrystallized during this event.

The third event (T_3) involved the tectonic transport of the surrounding metamorphic rocks including also portions of the Rannach serie schists which were inserted within the ultramafic massif. It also led to localized mylonitization due to which second-generation serpentinemylonite (M_3) was developed. This event was accompanied further by the formation of minute fracture-filling chrysotile asbestos within the serpentinite, and by the formation of high temperature- high pressure mineralogical assemblages in the Rannach serie schists which were inserted within this massif.

The fourth event (T_4) led to localized mylonitization and formation of third generation serpentine-mylonite (M_4). It was also accompanied by the formation of high-temperature mineral assemblages in the Hochgrössen gneiss in contact with the ultramafic massif.

This discovery has since opened up new avenues of research into the function of serpentinization as a process potentially responsible for the formation of economic nickel sulphide concentrations from non-economic nickel-bearing olivine rocks.

Thayer (1966), Ramdohr (1967) and others have shown that serpentinization is a process of dehydrogenation. The release of hydrogen during serpentinization results in the formation of a reducing environment. There, the respective elements may react and result in the formation of lower temperature Ni, Cu and Fe-sulphides. In case of intensely reducing conditions and with the complete extraction of sulphur by the developing low-temperature sulphides, the remaining Ni and Fe form the Ni-Fe alloy (awaruite) and the remaining Cu then forms native copper (Ramdohr, 1967). The applicability of these considerations to the evolution of the Hochgrössen Serpentinite, which was subjected to localized CO_2 metasomatism, is demonstrated by the presence of awaruite and of native copper in association with magnetite in the chromite concentrates.

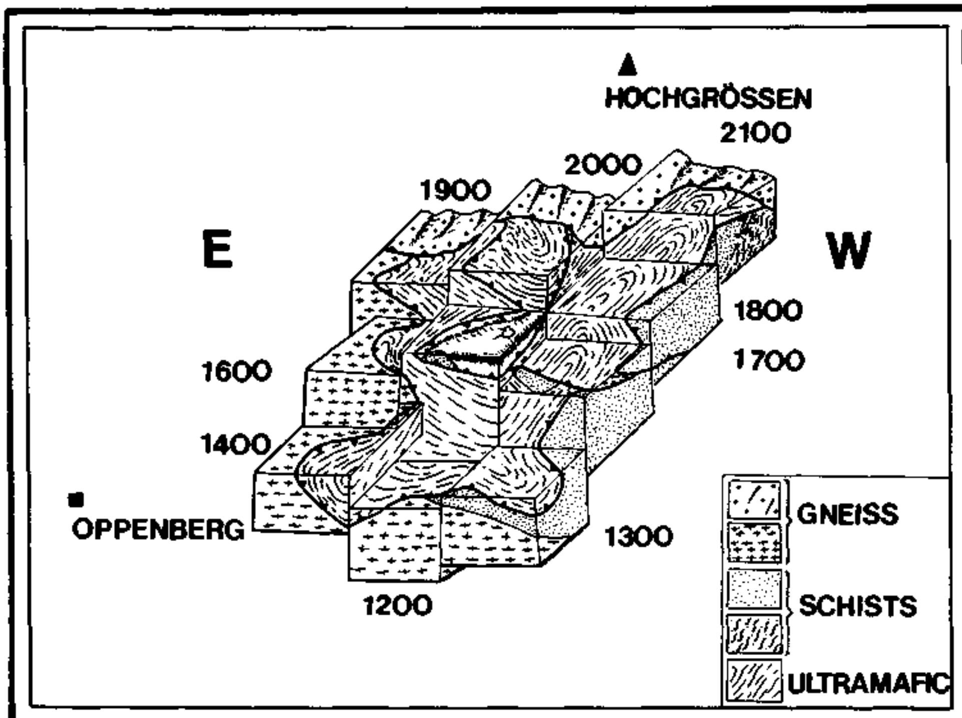

Fig. 1: A diagrammatic three-dimensional representation of the Hochgrössen ultramafic massif.

Electron Probe analyses of the Hochgrössen chromites illustrate that they are essentially mixed-crystal spinels in which the Al-, Mg- and Ferrochromite end-members are dominant. During serpentinization these spinels tend to lose Mg and Al and correspondingly get enriched in Fe^{+2} and Fe^{+3}. This resulted in the development of ferrichromite and ultimately of magnetite as an end-product of serpentinization. This is illustrated in Table 3.

Mineralization

The Hochgrössen ultramafic rocks are characterized by the occurrence of uneconomic chromite and sulphide mineralizations. The chromites occur both as concentrates and as disseminations. As concentrates, they form schlierens, bands and lenticular bodies not excluding 80 cm × 20 cm. They are generally conformable with the foliation trends of their

Table 1: Relationships between deformation and readjustment.

ROCK TYPE	T1 / M1	T2 / M2	T3 / M3	T4 / M4
SERPENTINIZED DUNITE	M Y	S E R P	M Y L O N	M Y L O N
SERPENTINITE		E N T I	I T asbestos	I T
SERPENTINE MYLONITE	L O N 1	N I Z A T	I Z A 2	I Z A 3
TALC-CARBONATES		I. O N	T I O N	T I O N
GARNET-AMPHIBOLITE	I T	R E G. M		
RANNACH-SERIE ROCKS	I Z A	E T A M O	TECTONIC TRANSPORT HIGH T-P ASSEMBLAGE (LOCAL)	
BÖSENSTEIN GNEISS	T I O N	R P H I S M		
HOCHGRÖSSEN GNEISS		HIGH T-P ASSEMBLAGE		

enclosing rocks. As concentrates, chromite is restricted in occurrence to the central part of the ultramafic massif; as a disseminated mineral however, it is distributed throughout the ultramafic body.

The sulphides are disseminated in the micropscopic scale throughout the ultramafic body. Macroscopically, however, they are encountered as very fine grains on the south-western outcrops of the massif. The sulphides and chromites were intensely readjusted during serpentinization, but some are still present as relict primary minerals (Table 2).

Table 2: **Mineralogy of the sulphides and the chromian spinels**

ROCK TYPE	PRIMARY MINERALS	T1	T2	T3	T4
		M1	M2	M3	M4
U	PENTLANDITE		HEAZLEWOODITE		
L	CHALCOPYRITE		MILLERITE		
T			BORNITE		
R			VALLERIITE		
A			COVELLITE		
M			PYRRHOTITE		
A			AWARUITE		
F			NATIVE COPPER		
I	Mg-CHROMITE		Fe^{+3}-CHROMITE		
C	Al-CHROMITE		MAGNETITE		
S	Fe^{+2}-CHROMITE				

The primary sulphides are essentially pentlandite and chalcopyrite. They are encountered in the serpentinized dunite. Pentlandite was to a large extent altered during serpentinization to form ***heazlewoodite, millerite*** and ***valleriite.*** The former two minerals were observed to occur along grain-boundaries and cleavage directions within pentlandite. Valleriite tends to occupy grain-boundaries between pantlandite and the silicates. This is probably due to the release of Mg from the silicates during serpentinization. Part of this Mg is then incorporated into the lattice of valleriite. Gersdorffite (Ni, Co, Fe) AsS, another secondary sulphide formed during serpentinization has been identified by electron-probe microanalysis. Ramdohr (1970) mentions gersdorffite, widely known as an integral constituent of certain silver-bearing vein deposits, from late-hydrothermal mineralizations at Sudbury, Ontario. Chalcopyrite has partly been altered to form bornite and covellite.

Table 3: **Magnetite as end-product of serpentinization**

	I Wt%		II Wt%		III Wt%		IV Wt%	
	core	rim	core	rim	core	rim	core	rim
Cr_2O_3	54.77	13.22	39.08	1.27	33.44	1.02	38.93	1.26
Al_2O_3	9.37	0.37	1.56	0.15	0.98	0.00	1.11	0.00
Fe_2O_3	6.93	26.81	15.63	30.31	19.55	29.90	16.88	29.13
FeO	15.69	54.86	35.35	61.55	44.23	67.64	38.17	65.89
MgO	11.47	2.45	6.57	3.36	0.47	0.06	2.14	1.34
MnO	1.36	0.75	2.40	0.32	0.94	0.08	1.60	0.11
SiO_2	0.18	0.14	0.14	0.12	0.20	0.00	0.16	0.24
TiO_2	0.30	0.22	0.14	0.00	0.74	0.07	0.43	0.11
TOTAL	100.07	98.80	100.87	97.08	100.55	98.77	99.42	98.09

I Electron Probe analyses of chromite concentrates
II Electron Probe analyses of chromites in the serpentinized-dunite
III Electron Probe analyses of chromites in the serpentinites
IV Electron Probe analyses of chromites in the serpentine mylonite

It is, by now, a well-established fact that elements such as Ni, Cu, Fe, Mg and S are released from primary silicates and sulphides during serpentinization. These processes have, on the basis of electronprobe analyses, been quantified by Rucklidge (1971, 1972), who was the first to detect the presence of chlorine in serpentinization ,,channels".

A comparison of Electron Probe analyses of chromian spinels from Hochgrössen with alpine-type spinels from Yugoslavia and the USA indicates close compositional similarities (Table 4). These compositional similarities may reflect certain genetic connections. The significance of chromian spinels as petrogenetic indicators has first been outlined by Irvine (1965, 1967). At Hochgrössen, they clearly assist in conjunction with tectonic and geological parameters, in establishing the alpine-type character of the massif.

Table 4: A comparison of analyses of chromites from Hochgrössen with alpine-type chromites

	I	II	III
	Wt%	Wt%	Wt%
Cr_2O_3	52.00	53.03	52.60
Al_2O_3	14.86	13.77	13.20
Fe_2O_3	5.76	—	3.30
FeO	11.70	13.96	11.10
MgO	13.46	10.99	16.20
MnO	0.52	0.26	0.15
CaO	0.23	0.28	0.07
TiO_2	0.25	—	0.18
SiO_2	0.14	5.38	1.71
H_2O^+	n. d.		0.95
H_2O^-	n. d.	1.52	—
V_2O_3	n. d.	—	0.15
NiO	n. d.	0.18	0.17
TOTAL	98.92	99.37	99.78

I Chromian spinel from Hochgrössen
II Chromian spinel from Yugoslavia, after Grafenauer (1975)
III Chromian spinel from Oregon, USA, after Thayer (1964)
n. d. not determined
— values not given

Economic and geological significance of serpentinization

A comparison of electron probe analyses of relict olivines in the serpentinized dunite with average whole rock analyses of serpentinized dunite, serpentinite and serpentine-mylonite indicates intensive migration of Mg concomitant with increasing water-content during serpentinization (Table 5).

The migration of Mg can also be illustrated by a comparison of electron probe analyses of chromite concentrates with analyses of chromites in the serpentinized dunite; chromites in the serpentinites and chromites in the serpentine-mylonites (Table 6).

Table 5: **Migration of Mg with increase of water content during serpentinization**

	I Wt%	II Wt%	III Wt%	IV Wt%
SiO_2	43.02	38.00	39.00	35.00
Al_2O_3	0.00	1.62	2.42	1.33
Fe_2O_3	0.89	2.20	2.66	1.91
FeO	2.03	8.98	11.39	9.84
MgO	52.50	42.33	33.20	35.28
CaO	0.00	0.07	tr	tr
Na_2O	n. d.	0.05	0.06	0.06
K_2O	n. d.	0.03	0.04	0.04
TiO_2	0.00	0.08	0.10	0.07
P_2O_5	n. d.	tr	0.006	0.004
MnO	0.25	0.13	0.07	0.09
Cr_2O_3	0.06	0.44	0.48	1.60
NiO	n. d.	0.50	0.36	0.39
H_2O^+	n. d.	7.12	11.10	12.25
TOTAL	98.74	101.55	100.886	97.864

I Electron Probe analyses of olivine relicts in the serpentinized-dunite
II Whole-rock analyses of the serpentinized-dunite
III Whole-rock analyses of the serpentinite
IV Whole-rock analyses of the serpentine-mylonite
n. d. not determinded

Table 6: **Migration of Mg with increase of water content during serpentinization**

	I Wt%	II Wt%	III Wt%	IV Wt%
Cr_2O_3	52.70	40.97	33.40	42.07
Al_2O_3	15.02	2.74	1.09	2.82
Fe_2O_3	5.81	14.11	19.24	15.24
FeO	13.15	31.92	43.50	34.46
MgO	11.71	7.76	1.14	1.14
MnO	0.52	2.33	1.06	1.79
SiO_2	0.12	0.00	0.19	0.21
TiO_2	0.14	0.22	0.69	0.36
TOTAL	99.18	100.05	100.31	98.09

I Electron Probe analyses of chromite concentrates
II Electron Probe analyses of chromites in the serpentinized-dunite
III Electron Probe analyses of chromites in the serpentinites
IV Electron Probe analyses of chromites in the serpentine-mylonite

These geochemical data thus support the text-book equation (Table 7), presented by Turner and Verhoogen (1960) that: by the addition of water to a certain volume of olivine, almost the same volume of serpentine will be formed with the removal in solution of excess Mg and silica. The amount of material which is removed is about 30% by weight of the original material (Thayer, 1966). This serves to illustrate the significance of serpentinization as a powerful geological and economic agent for the release and deposition of Mg-rich material.

This potential role of serpentinization is of particular interest within the alpine context: ultramafic und ultrabasic rocks, now partly or completely serpentinized, are abundant, and several huge magnesite deposits – whose origin is still a matter of conjecture – are present.

Table 7: Equation for the constant-volume serpentinization of olivine

5 $MgSiO_4$	+ 4 H_2O →	2 $H_2Mg_3Si_2O_9$	+ 4 MgO	+ SiO_2
Olivine	Introduced Water	Serpentine	(160 gm)	(60 gm)
(700 gm, 219 cc.)	(72 gm)	(552 gm, 220 cc)	removed in solution	

Summary

A summary of the general history of the Hochgrössen ultramafic massif is given in Fig. 2. There, metamorphic intensity, as indicated by the observed index minerals, is plotted against time as represented by the four successive deformational events to which the massiv was subjected.

The tectonic transport of the Hochgrössen massif probably was contemporaneous with its stage of emplacement (T_1 M_1). It was followed by a regional deformational as well as metamorphic event (T_2 M_2), the result of which is the intensive serpentinization (i. e. antigoritization) of the massif. During the waning stages of the latter phase, a tectonic break

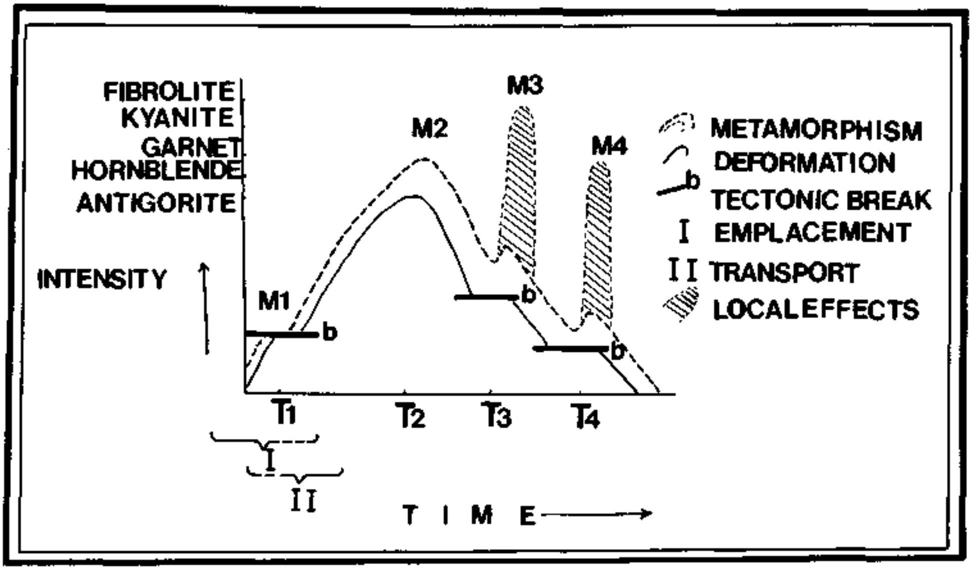

Fig. 2: Relationships between deformation and metamorphism.

occurred. This (T_3 M_3) was accompanied by localized development of high temperature-pressure mineral assemblages especially in the schists which were inserted within the ultramafic massiv during this event. The last event (T_4 M_4) was accompanied by localized development of high-temperature mineral assemblages. This occurred in the Hochgrössen gneiss in contact with the serpentine-mylonite at the southern termination of the ultramafic massif.

This review illustrates that the Hochgrössen ultramafic massif exhibits most of the characteristics considered typical for alpinetype ultramafic bodies. Since such bodies are distributed world-wide, a mechanism operating on a global scale should account for their emplacement. A detailed analysis of the Paleozoic Alps in terms of plate tectonics theory – as presented for the recent evolution of the Alpides of Southeastern Europe by Hadzi et al. (1974) – it not available yet and may, for obvious reasons, never become available. However, it is tentatively proposed that the Hochgrössen massiv and the Kraubath massiv represent parts of ultramafic and ultrabasic rock assemblages which were tectonically transported direct from the mantle along the continental margin of a Palaeozoic plate. The characteristics of this plate were largely obliterated by the Mesozoic alpine orogeny. The results of continuing investigations of these aspects will be published elsewhere.

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References

BACHMANN, H.: Die Geologie des Raumes Oppenberg bei Rottenmann, Steiermark. – Verh. Geol. B. A. Wien, 1964.

GRAFENAUER, S.: Ore Petrology of ultramafic associations in Yugoslavia Slovenska Akademija Znanosti in Umetnosti Razred za Prirodos Lovne Vede. Classis IV. Historia Naturalis Dela-Opera 22 (Slovenian with English summary). 1975.

HADŽI, E., PANTIĆ, N., ALEKSIĆ, V., and KALENIĆ, M. The Alpides of Southeastern Europe in the Light of Plate Tectonics. In: Metallogeny and Concepts of the Geotectonic Development of Yugoslavia (S. JANKOVIĆ, Editor), Faculty Min. Geol., Univ. Belgrade, 275–310. Beograd 1974.

IRVINE, T. N., Chromian Spinel as a petrogenetic indicator, Part I, Theory. – Can. J. Earth Sci., 648–672, Ottawa 1965.

IRVINE, T. N., Chromian Spinel as a petrogenetic indicator, Part II, Petrologic application. Can. J. Earth Sci., 4, 1–103, Ottawa 1967.

METZ, K., Tektonische Übersicht der Umrahmung des Bösenstein Massivs, Steiermark. – Verh. Geol. B. A. – Wien, 1964.

METZ, K., Geologische Karte der Steiermark, M: 1 : 300.000, Graz: Akat. Druck- u. Verlagsanst. 1957 (Steiermark-Atlas, Bl. 6).

RAMDOHR, P., A widespread Mineral Association connected with Serpentinization. – N. Jb. Miner. Abh. 107, 241–265, Stuttgart 1967.

RUCKLIDGE, J. C., Mobilisation of nickel and platinum metals during serpentinisation of ultramafic rocks. – Platinum Conference, University of Melbourne, 1971.

RUCKLIDGE, J. C., A study of the redistribution of Ni in the serpentinization of olivine. – 6th Internat. Conf. X-Ray Optics and Microanalysis, Osaka, Japan, 743–747, 1972.
THAYER, T. P., Principal features and origin of Podiform chromite deposits and some observations on the Guleman-Soridag District, Turkey. – Econ. Geol. 59, 1497–1524, Blacksburg 1964.
THAYER, T. P., Serpentinization considered as a constant volume metasomatic Process. – Am. Min. 51, 685–710, Washington D. G., 1966.
TOLLMANN, A., Geologie von Österreich. Bd. 1. Wien: Franz Deuticke 1977, 766 pp.
TURNER, F. and VERHOOGEN, J., Igneous and Metamorphic Petrology. 2nd ed. – New York, London, Toronto: Mc Graw-Hill, 1960.

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