MITT.ÖSTERR.MINER.GES. 143 (1998)

# SODIC CORDIERITES: COMPARISON OF NATURAL DATA AND INCORPORATION EXPERIMENTS

by

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MinPet 98

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## Introduction

Cordierite ($[Mg,Fe]_2Al_4Si_5O_{18}.n[Na,H_2O,CO_2$, etc.] is an interesting mineral phase in metapelitic granulites, amphibolites and hornfelses as well as in igneous rocks and is considered a mineral phase useful for thermobarometric determinations. Sodium and fluid species like $H_2O$ and $CO_2$ are located in the channels of the cordierite structure, which are build up by six-folded $Si_4Al_2O_{18}$-rings. Analyses of natural cordierites from different geological environments display decreasing Na values with increasing formation temperatures (Fig. 1). Previous pilot-experiments with Mg-cordierite, albite and NaOH, respectively, have shown a linear decrease of the Na content with increasing temperature at very small pressure dependence (MIRWALD, 1986). Currently, an experimental study is in progress concerned with incorporation of sodium into Mg-cordierite at elevated pressures and temperatures, in order to test its possible use as a geothermometer.

## Field data

Cordierite occurs in different geological environments. Pre-eminentely, cordierite is a product of metamorphism ranging in its P-T-conditions from 550 to some 950°C and up to some 1.1 GPa, however, cordierite occurs also in magmatites.

A) High-temperature, low-pressure conditions are often realized in thermally metamorphosed sediments of the hornfels facies. B) Most frequently, cordierite occurs in regionally metamorphosed metapelites, comprising a wide temperature range from 550 up to 800°C at medium pressures, with an emphasis on amphibolitic conditions. C) Cordierite is also a characteristic mineral in granulitic terrains with P-T-conditions from 700 to 950°C at pressures ranging from 0.4 to 0.9 GPa. D) Cordierite-anthophyllite associations are found in high-grade metamorphic terrains, variously attributed to complex metamorphic and metasomatic processes. E) Cordierite-bearing migmatites should be distinguished from the other groups, because of the fact, that cordierite may have been in direct contact with partial melt at temperatures above 700°C and relatively high $P_{H2O}$. F) Cordierite-bearing acid aluminous igneous rocks are not uncommon and cordierites are considered to be either xenolitic or a genuine magmatic phase.

In Fig. 1, a number of cordierite analyses from the literature has been plotted with different symbols corresponding to there different types of origin. It is obvious, that the highest Na values are found in hornfelsic or magmatic cordierites, low Na content is common in granulites. Regional metamorphic cordierites usually exhibit intermediate Na values.

**Experimental work**

Recently a number of new experiments in the temperature range of 500 - 850°C between 0.3 and 0.8 GPa have been performed. The experiments were conducted in end-loaded piston cylinder apparati. Modified NaCl assemblies (MIRWALD et al., 1975) and new $CaF_2$-cells developed for T > 800°C were employed. As standard starting materials, we used 20 mg synthetic Mg-cordierite together with albite-glass (2 mg) and $H_2O$ (9 mg) welded into Au capsules. Further, a few experiments were performed with $CO_2$-component in addition. As $CO_2$ source served oxalitic acid dyhydrate and silver oxalate, respectively. The initial $CO_2$ to $H_2O$ ratii were 1 1 and 9 : 1, respectively. All products were analysed by microprobe and XRD.

The experiments base on the investigation of the system Mg-cordierite + albite + $H_2O$ ($\pm CO_2$). The assumed incorporation mechanism is $NaAlSi_{-1}$. In order to check a possible influence through a missing silica buffer, we performed a douple capsule experiment: One capsule contained the standard material, the other in addition quartz. We found no difference in the Na values. From this we deduce that our experimental system provides a good model for this incorporation study.

The results from incorporation experiments obtained under the condition of $P_{total} = P_{H2O}$ suggest a nearly linear decrease of the Na content between 500 and 700°C (Fig. 2). The same kind of experiments exerted between 700 and 850°C showed a significantely higher Na content. However, the data still maintain a negatively sloped correlation. This finding seems related to the formation of eutectic (partial) melt > 700°C (at some 0.5 GPa). Separate experiments, relying on quenching and differencial pressure methods, confirmed an eutectic on the join cordierite-albite at these P-T-conditions. Sodium incorporation experiments in presence of $CO_2$ ($H_2O : CO_2 = 1$) yielded lower Na contents (see Fig. 2). At 800°C sodium is below the detection limit. Runs with the higher $CO_2$ to $H_2O$ ratio of 9 1 yielded even lower Na contents than those with the 1 1 ratio.

**Discussion**

The experiments confirm the principal finding by MIRWALD (1986), the data reveal, however, a considerable higher complexity than inferred from the pilot-experiments. So, in contrast to previous interpretations by KNOP (1996) the new data suggest a dependence of the Na incorporation from the type of the sodium donator (albite-glass + $H_2O$ or 1n NaOH-sol.). The present results lead to the conclusion, that the use of a solid sodium phase (here: albite) yields results close to natural conditions. Pressure and Si-Al order of cordierite seem to be less important for the behavior of Na incorporation. The experiments gave no confirmation or disproof of the assumed exchange reaction $NaAlSi_{-1}$.

The process of Na incorporation is not only influenced by the temperature, but also by the $Na^+$ activity. This may reduce in some way the applicability of the geothermometer in case the fluid regime of the paragenesis is not known. On the other side, this offers the possibility to elucidate this problem.

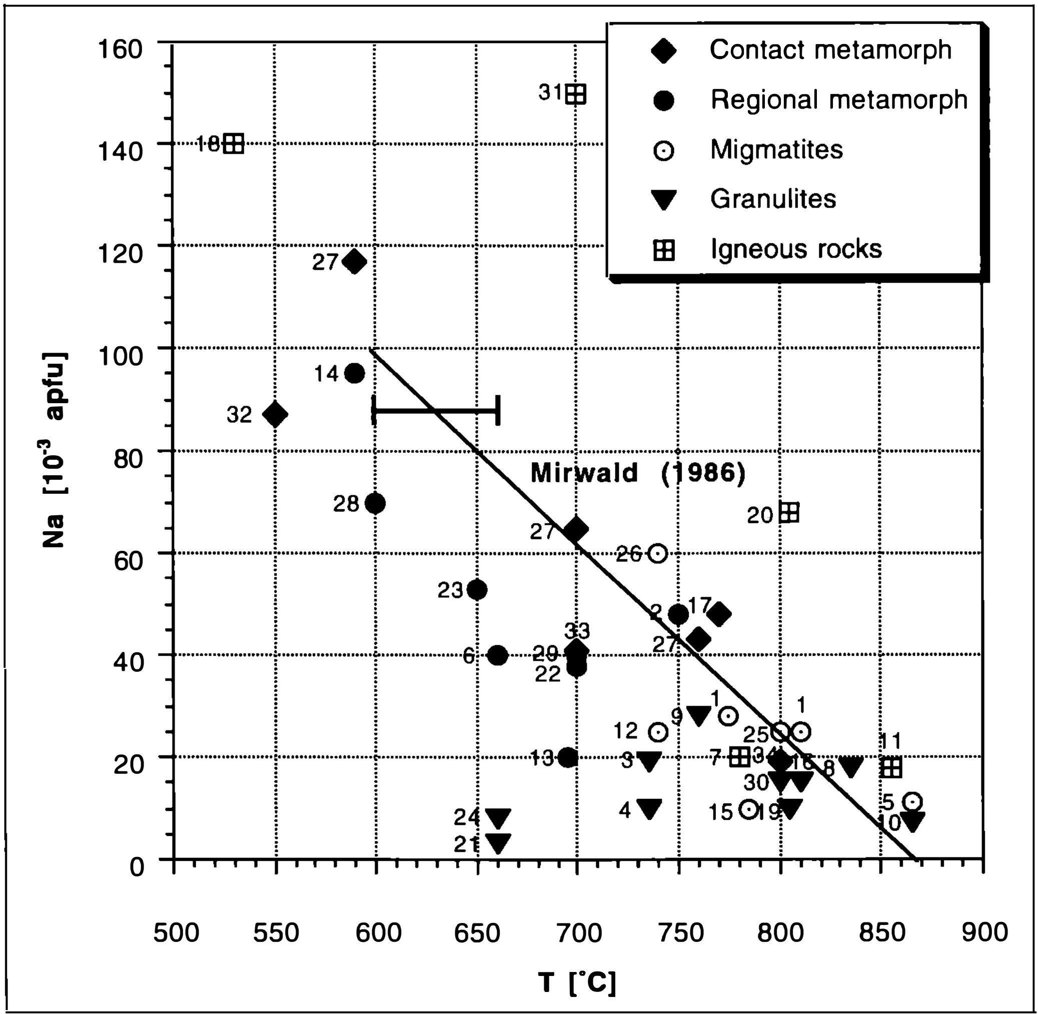


*Fig. 1*

*Analyses of natural cordierites from different geological environments. Mean Na contents are plotted versus authors estimations of formation temperatures of the whole rock. Line with uncertainty bar represents the results of the pilot-study by MIRWALD (1986). (Data sources: see page 319).*

Comparing experimental data (Fig. 2) and field data (Fig. 1), a number of similar features with regard to sodium incorporation in cordierite may be recognized:

- At low temperatures (< 700°C) our cordierites from runs at $P_{total} = P_{H2O}$ show the similar linear temperature dependence as displayed by cordierites from regionally metamorphosed rocks.
- Our results from $CO_2$-bearing runs ($P_{total} > P_{H2O}$) which yielded low Na contents seem possibly comparable to low sodium cordierites described from granulites.
- The experiments at T > 700°C at $P_{total} = P_{H2O}$ combined with significantely higher Na contents indicate partial melting. We interpret this by a - compared with the subsolidus experiments - relatively higher $Na^+$ activity due to the presence of melt. We infer from this principal similarities with conditions in partial molten metapelites.

***Data sources (Fig. 1)***

*1 Anatexite, Naantali, SW-Finland (Meier, 1992)*
*2 Metapelite, Kiranur, S India (Geiger, pers. comm.)*
*3 Metapelite, Chiaravalle, Calabria, Italy (Geiger, pers. comm.)*
*4 Metapelite, Colombo, Sri Lanka (Geiger, pers. comm.)*
*5 Anatexite, Finish Lapland (Geiger, pers. comm.)*
*6 Metapelite, Manifouwadge, Ontario, Canada (Geiger, pers. comm.)*
*7 Granite, Ivanov, Ukraine (Geiger, pers. comm.)*
*8 Granulite, Finish Lapland (Geiger, pers. comm.)*
*9 Granulite, Sila grande, Calabria, Italy (Le Breton, 1983)*
*10 Granulite, Ajitpura, Rajastan, India (Geiger, pers. comm.)*
*11 Rhyolithe, Central Victoria, Australia (Clemens & Wall, 1984)*
*12 Migmatite, Sauwald, S Bohemian Massif, Austria (Knop et al., 1995)*
*13 Gneiss, Ajitpura, Rajasthan, India (Sharma & MacRae, 1981)*
*14 Low amphibolite, Central Brittany, France (Schulz et al., 1997)*
*15 Migmatite, Pulur Massif, NE Turkey (Topuz et al., 1996)*
*16 Granulite, E Himalaya, China (Liu & Zhong, 1997)*
*17 Xenolith, Ortler, S Tyrol, Italy (Mair, 1998)*
*18 Monzogranite, Tuscany, Italy (Cavaretta pers. comm.)*
*19 Granulites, Finish Lapland (Hörmann et al., 1980)*
*20 Granite, Velay anatectic dome, Massif Central, France (Montel et al., 1992)*
*21 Gneiss, Sonapahar, Assam, India (Lal et al., 1978)*
*22 Gneiss, Sioux Lookout, English river Gneiss belt, N Ontario, Canada (Harris, 1976)*
*23 Metapelite, Nain Complexe, Labrador, Canada (Berg, 1977)*
*24 Gneiss, McCullough range, Nevada, USA (Young et al., 1989)*
*25 Migmatites, Scottish Caledonia, Great Britain (Ashworth & Chinner, 1978)*
*26 Migmatite, Fosdik Mountains, Mary Byrd Land, Antarctika (Smith, 1996)*
*27 Contact metamorphosed metapelites, Kos, Greece (Kalt et al., 1998)*
*28 Epidote-amphibolites, mean of 180 samples (Lepezin, pers. comm.)*
*29 Amphibolites, mean of 190 samples (Lepezin, pers. comm.)*
*30 Granulites, mean of 150 samples (Lepezin, pers. comm.)*
*31 Granites, mean of 12 samples (Lepezin, pers. comm.)*
*32 Hornfelses, low-grade, mean of 13 samples (Lepezin, pers. comm.)*
*33 Hornfelses, medium-grade, mean of 18 samples (Lepezin, pers. comm.)*
*34 Hornfelses, high-grade, mean of 25 samples (Lepezin, pers. comm.)*

- In principal, contactmetamorphic cordierites should offer a good occasion to test our data, due to the steep temperature gradient given. The results by KALT et al. (1998) (Fig. 1, date 27) and LEPEZIN (pers. comm.) (Fig. 1, data 32-34) confirm the temperature dependence discussed.
- Igneous cordierites often display abnormal high Na values (Fig. 1, data 18, 20 & 31), but also normal contents (Fig. 1, data 7 & 11). However, it is well known (e. g. ČERNÝ et al., 1998) that the sodium content in cordierites of this provenance is often related to considerable amounts of lithium and beryllium. A way to check such disturbancies is the determination of the lattice constants (cf. MIRWALD, 1998).

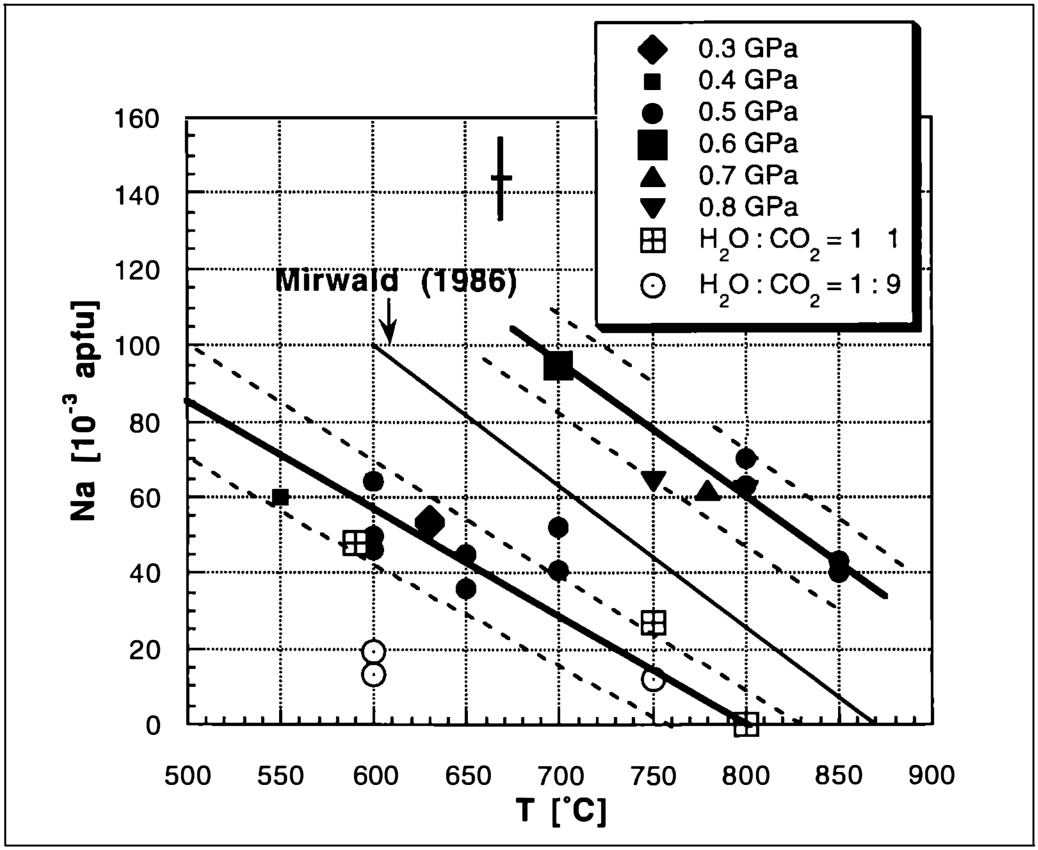


*Fig. 2*

*Results from Na incorporation experiments with albite-glass as a Na donator. Data are median values, the uncertainty range is indicated by the cross. The thin line represents the results of MIRWALD (1986) with an T uncertainty of ± 30K. Thick lines give the estimated correlation between Na content and temperature, accompanying dotted lines show the range of uncertainty.*


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