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Evolution of the assemblage magnesite and quartz by metasomatic reactions within metadolomites during retrograde metamorphism in the southern Damara Orogen, Namibia

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A long-lasting fluid infiltration event influenced mineral reactions during retrograde metamorphism in parts of the southern margin zone of the Damara Orogen. Talc was formed in many places in metadolomites in voluminous masses by infiltration of silica-bearing aqueous fluids into the hot rock. The Ca from the decomposition of dolomite did not precipitate in the form of calcite because it was removed by the metasomatic fluids. At the end of this process talc decomposed under the influence of CO_2-rich fluids to form magnesite + quartz.

Introduction

Metacarbonates are widespread within the southern margin zone of the Damara Orogen. The grade of metamorphism in this part of the orogen increases from the southern edge of the Damara succession in a northerly direction approximately perpendicular to the structural-stratigraphic zonation shown in Figure 1. General as well as detailed information about the geology and metamorphism of the Damara orogen are given in two volumes edited by Miller (1983) and by Martin and Eder (1983).

The carbonate rocks in the southern part of the Damara Orogen contain tremolite and talc as characteristic metamorphic minerals. There are two generations of tremolite. The first generation is found over more or less the whole southern area of the Damara Orogen and formed syntectonically. This generation is older than the talc (Puhan, 1988). A second generation of tremolite is found only in the more nothern part. This second generation formed post-tectonically and is of the same age as the talc. The existence of a younger generation of tremolite and talc is the result of fluid infiltration events in the southern Damara during retrograde metamorphism. The evolution of assemblages will be explained with the help of Figure 2.

The first generation of tremolite was formed at or above conditions given by the equilibrium curve of reaction (2). This happened at pressure conditions higher than those of the example of Figure 2. Towards higher pressures the equilibrium surface of reaction (2) expands with respect to Xco_2. Puhan (1995) has shown that at high pressures (>6-8 kb) the formation of talc within siliceous dolomites is possible only at extremely H_2O-rich fluid compositions and is therefore improbable.

During retrograde metamorphism, fluid infiltration with fluid compositions given by the example of point (b) in Figure 2 caused the older tremolite to react with calcite and the CO_2 of the fluid to form dolomite + quartz. If such a CO_2-rich fluid enters a tremolite-calcite assemblage, a special corona texture may be formed (Puhan, 1988). Simultaneously, dolomite + quartz react to form talc and calcite where the infiltrating fluids were of favourable composition, corresponding to point (c). At the higher temperature of the northern area, a contemporaneous fluid with the composition of example (a) in Figure 2 produced tremolite of a younger generation in the siliceous dolomites.

With time the infiltrating fluids almost completely erased the older tremolite in the southern part. Therefore, the southern part is dominated by talc and is called

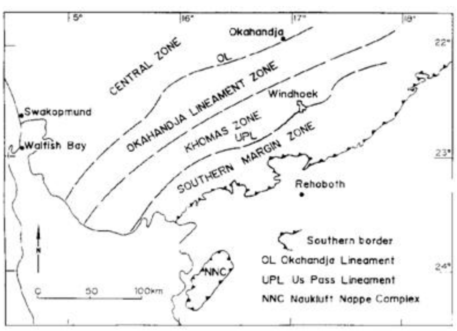

Figure 1 : Structural-stratigraphic zones of the southern Damara Orogen after several publications in Miller (1983)

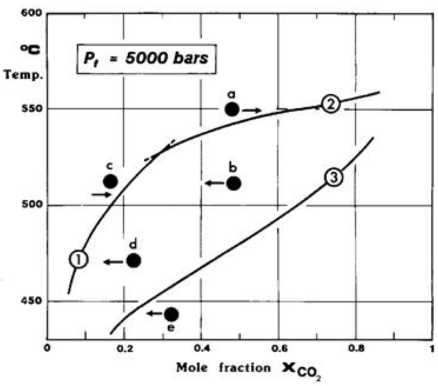

Figure 2 : Relevant mineral equilibria to explain reaction products.

(1) 3 dolomite + 4 quartz + 1H_2O = 1 talc + 3 calcite + 3CO_2

(2) 5 dolomite + 8 quartz + 1H_2O = 1 tremolite + 3 calcite + 7CO_2

(3) 3 magnesite + 4 quartz + 1H_2O = 1 talc + 3CO_2

(equilibria after Gottschalk, 1997)

the talc field. The northern area is dominated by tremolite of the younger generation. It still contains tremolite of the older generation because the metamorphic grade in this part was in the stability region of tremolite throughout the infiltration events. This nothern area is thus called the tremolite field.

Between the talc field in the southern part and the tremolite field in the northern part, a zone with the assemblage

tremolite + talc + dolomite + calcite + quartz

is developed. The tremolite within this assemblage belongs to the older generation. This assemblage marks the pressure and temperature of the transgression surface from the talc field to the tremolite field at the end of the period of strong fluid infiltration events. The waning of fluid infiltration during decreasing pressure and temperature brought the migration of this five-mineral zone assemblage towards the north to a standstill. In other words, the talc field stopped migrating to the north because the fluid supply for the prograde talc reaction and the retrograde alteration of tremolite stopped. The evolution and significance of the five-mineral assemblage within this scenario is given by Puhan (1995).

In the southern talc field, the metasomatism was strong in places and lasted long enough for the talc to be retrogressively transformed during decompression and cooling. Under the influence of the infiltrated fluid, the magnesian component of the talc first precipitated in the form of dolomite (point (d) in Fig. 2) as long as an appropriate amount of Ca was available, and finally in the form of magnesite (point (e) in Fig. 2).

This paper deals with the evolution of metasomatic assemblages in the talc field, and with the development of microtextures associated with these transformations. The constraints given in this paper are based on investigations of thin sections from several outcrops. Regional behaviour is deduced from these local observations.

Behaviour of the fluid within the metadolomites

In the metadolomites, small amounts of early pore fluids may be bound in the first generation of tremolite. The dehydration of tremolite during metamorphic decompression and cooling (point (b) in Fig. 2) may serve as a small local source of H_2O which dilutes a CO_2-richer fluid while the rock volume on the pressure-temperature path was passing through the stability region of talc, as described by Puhan (1988, 1995).

The volume and textures of talc and tremolite of the younger generations indicate that the fluid for the reactions infiltrates the carbonate rock system. The nature of fluid flow changes over small distances. Large reaction pods within the dolomites are sited along fissures. The wallrocks are more or less penetrated by a network of tiny cracks following grain boundaries as well as cutting grains. Rarely, all kinds of fluid-rock interactions are visible within one outcrop. The peak of fluid infiltration in the southern margin zone was certainly a post-deformational process during the time of decompression and extension. The ingress of the fluid in many cases was a abrupt event: an injection of fluid into a hot rock. The infiltration process was concentrated in the southern talc field below a temperature of about 520°C and 5 kbars (Puhan, 1995) and may have ended in the very southern parts in a temperature and pressure regime where the fluid condenses to liquid and vapor phases. Exsolution is very likely because of the high salinity of some fluids trapped within quartz from metadolomites of the southern margin of the orogen (Behr *et al.*, 1983).

Formation of talc

Dolomite is by far the dominant constituent of the carbonates as can be deduced from virtually unmetamorphosed carbonate rocks from the southernmost parts of the Damara succession. Fluid infiltration into the dolomites while P-T conditions are within the talc forming field (Puhan, 1995) may produce talc either if quartz is present as chert, or if silica has been introduced to the system dissolved in an aqueous fluid. The reaction can be formulated

(1) 3dolomite + 4quartz + 1H_2O $\rightarrow$ 1talc + 3calcite + 3CO_2.

If only a small amount of fluid enters the dolomites the system is almost closed, controlling the composition of the fluid as long as the solid phases to the left of the equation are in excess. Talc will be formed and the Ca from the decomposition of the dolomite precipitates in the form of calcite. The parageneses resulting from this reaction (1) will be talc + calcite + dolomite + quartz. This assemblage is a constituent of many of the dolomitic marbles of the southern margin zone. There is every reason to believe that the assemblage containing all phases involved in reaction (1) does not necessarily correspond to P-T-X_{fluid} conditions of the equilibrium surface of reaction (1). The progress of the reaction will be controlled above conditions of an equilibrium surface by the amount of fluid, the composition of the fluid and by the type of fluid flow (reaction conditions as for examples (c) or (a) in Fig. 2). Sometimes the above-mentioned assemblage is associated with relicts of the older generation of tremolite. There are no indications that talc was formed directly from tremolite.

Another type of marble consists of abundant dolomite with minor amounts of talc and a little quartz. The talc was formed along microcracks. Calcite cannot be found in these rocks. Layers of this type may have a thickness of more than 10 m. Within these formations the Ca from the decomposition of the dolomite has not precipitated in the form of calcite. All the Ca was taken away completely by the fluid. In these cases the rock system acted like an open system for sufficient time with a fluid which was undersaturated with respect to calcite. The same situation can be found within large reaction pods which consist only of talc and dolomite. The mobility of Ca is documented in the photomicrograph of Figure 3 where the calcite is dispersed along fluid pathways often far away from talc (calcite stains dark, dolomite colourless). Such fluid pathways are easily recognizable with the help of the stained calcite. Samples like that of Figure 3 show a connecting link between parageneses with and without calcite and proves that the transformation follows reaction (1).

Talc deposits with relict dolomite will be formed if the composition of the infiltrating fluids are suitable and the amount of the fluid and time are sufficient. The silica of such transformations is introduced with the fluid. Silica may precipitate in the form of quartz, as documented by the photomicrograph of Figure 4 taken from a sample containing much talc together with some relict dolomite. Calcite does not precipitate. Single grains or clusters of dolomite are seen to be more or less enclosed in quartz. Such textures are interpreted as a reaction of dolomite with a silica-rich fluid. The enveloped single grains or clusters of dolomite are relicts of former dolomite masses. Quartz precipitation may be caused by a CO_2-halo around the reacting dolomite because quartz will be oversaturated with increasing Xco_2 (Novogorodov, 1975). From the distribution of samples with such a corona texture it is believed that they were formed near the end of the talc-forming period. Electron microprobe analyses of the minerals in mutual contact in Figure 4 show dolomite with very little Fe and a small excess of Mg.

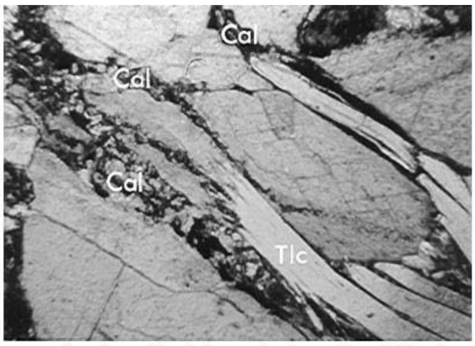

Figure 3: Dolomite with flakes of talc and mobilized calcite (stained dark) along fluid pathways. Long edge of photomicrograph 850 microns. Crossed nicols

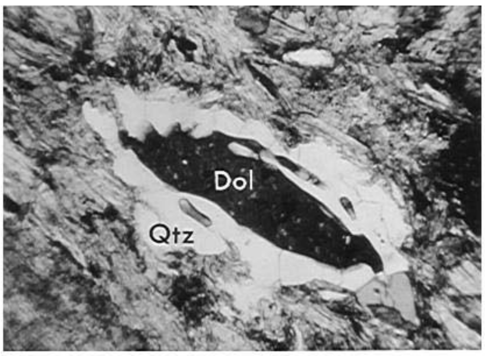

Figure 4: Quartz enveloping dolomite within a matrix of talc. Long edge of photomicrograph 850 microns. Crossed nicols.

Decomposition of talc

The next step in the metasomatic transformation of former dolomites is the decomposition of talc. Talc decomposes following the reaction

(3a) talc + CO_2-rich fluid → magnesite + quartz + H_2O-rich fluid.

Metasomatic evolution of the assemblage magnesite + quartz following reaction (3a) was also discussed by Johannes (1970). Dolomite may be enclosed in magnesite if dolomite of the former stage is still present within the assemblage as shown in Figure 5. The quartz from the decomposition of talc may contain relict talc as demonstrated in Figure 6. It is obvious from many examples of talc decomposition that quartz replaces the former talc.

The final stage of the metasomatic transformation of talc produces a carbonate layer consisting almost completely of magnesite with very little dolomite and some quartz. Quartz grains in thin sections of such samples mostly form groups where the grains are in optical continuity, as illustrated in Figure 7. Optical continuity be-

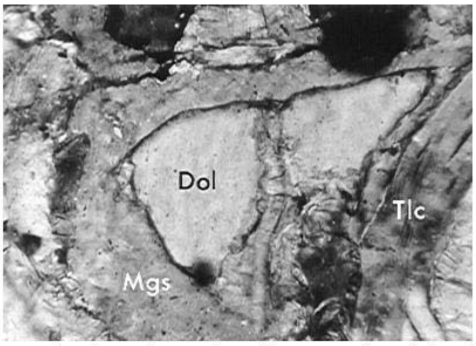

Figure 5: Dolomite grain enveloped by magnesite. Flake of talc on the right side. Long edge of photomicrograph 430 microns. Crossed nicols.

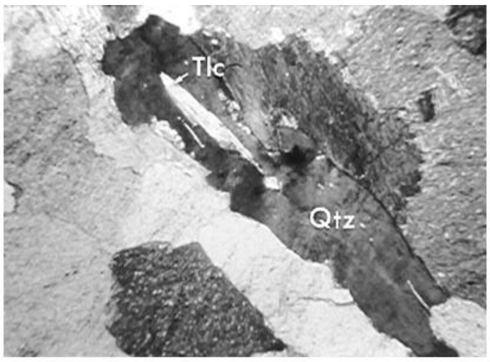

Figure 6: Relic flake of talc enclosed in an elongated quartz grain from the decomposition of talc. Matrix consists of dolomite and magnesite (upper left hand rim of the quartz grain). Long edge of photomicrograph 1000 microns. Crossed nicols.

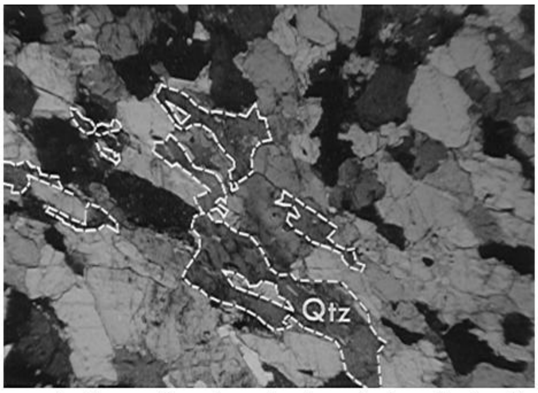

Figure 7: Group of quartz grains in optical continuity. Such quartz grew as an interconnected network at grain boundaries of magnesite. Tiny flaky white inclusions within the quartz grains are relict talc (see text). Long edge of photomicrograph about 3300 microns. Crossed nicols

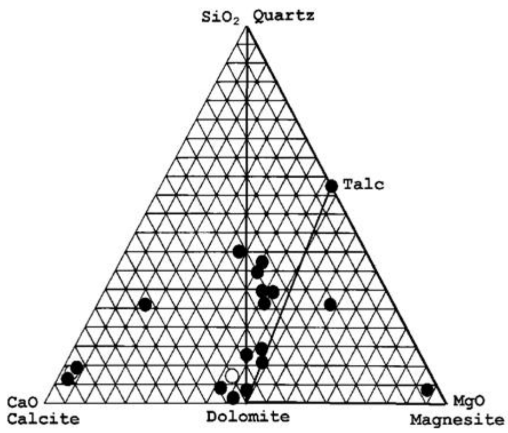

Figure 8: Graphical representation of the composition of metacarbonates of the southern Damara Orogen. For further explanation see text. The distribution of compositions is not of any statistical relevance. Open circles show average composition of limestones and dolomites of the Damara Sequence (from Schneider, 1983)

tween populations of such isolated blebs suggests that the quartz grew as an interconnected network. A similar texture has been desribed by Holness *et al.* (1989) where olivine growth along grain boundaries from grain triple points forms an interconnecting network. Quartz grains like those of Figure 7 contain tiny inclusions of talc, sometimes submicroscopic. Electron microprobe analyses of such milky grains of quartz show a considerable amount of magnesium (up to 4 wt% MgO).

Within samples such as that shown in the photomicrograph of Figure 7, small tabular talc flakes sometimes occur along fissures. These flakes are interpreted to be a new but very late generation of talc formed from magnesite + SiO_2 + fluid, indicating fluctation of conditions during the general cooling process.

Graphical representation of assemblages

Common staining techniques were used to differentiate between carbonates within a thin section. On the other hand it is easy to predict an assemblage in a sample with the help of an analysis of the main oxides MgO, CaO and SiO_2. These oxides were converted into molecular ratios and used for graphical representation in a trianglar diagram (e.g. Winkler, 1979). All samples in Figure 8 are from the southern talc field. Assemblages with an excess of calcite plot in the left half triangle. This means there is more calcite in the rock that corresponds to calcite from reaction (1). A rock composition containing only dolomite + quartz is represented by a point along the line dolomite - quartz. This is also the case for an assemblage dolomite + quartz + talc + calcite as long as the amount of Ca is sufficient to convert the Mg bound in talc into dolomite (closed system). If Ca is partly removed from the sample by the metasomatic fluid, the assemblage plots in the field of dolomite - talc - quartz near the dolomite - quartz line. An association of dolomite + talc with different proportions of the two minerals plots on the line dolomite - talc (all SiO_2 fixed within talc). Assemblages of dolomite + magnesite + talc ± quartz are represented by points in the lower right hand field. A mineral association like that shown in the photomicrograph of Figure 5 plots in the middle of the field and that of Figure 7 near the magnesite corner.

Summary and conclusions

Metasomatic talc deposits are widespread in the southern part of the Damara Orogen. All such deposits were formed during decreasing metamorphic P-T conditions. Most SiO_2 required to form talc masses from dolomite was brought into the rock system by a silica-rich fluid. Large-scale removal of Ca by the metasomatic fluids has taken place resulting in a talc + dolomite assemblage being common. At the end of the metasomatic processes, talc decomposed under the influence of a CO_2-bearing fluid to form magnesite. Coronas of magnesite around dolomite, or layers of sometimes pure magnesite were formed. Quartz within magnesite layers was generated by the release of SiO_2 during the decomposition of talc and forms an interconnected network of grains.

Metasomatic assemblages vary greatly within small rock volumes. The examples shown here are selected to demonstrate the continuous metasomatic evolution from a siliceous dolomite to a magnesite rock. Until now, no examples have been found which show formation of abundant talc from magnesite + quartz + fluid.

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