Grain coarsening and hydrothermal alteration in metacarbonates of the Damara Orogen, Namibia

Poster

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Introduction and geological background

Grain coarsening is a process that occurs in a wide variety of rock types. The application of grain growth theory to natural geologic materials has its beginnings in the theoretical foundations of the metallurgical and material sciences. Two types of grain growth can be statistically defined: 1) normal grain growth describing a uniform grain structure and 2) abnormal grain growth, where some grains grow more rapidly in size at the expense of matrix grains, thus creating a bimodal grain size distribution. This study aims to understand the grain coarsening phenomenon in metacarbonate rocks, to determine the mechanisms involved and to elucidate the role of fluids (e.g. hydrothermal alteration).

Metacarbonate units exhibiting coarsely crystalline fabrics, representing abnormal grain growth, and hydrothermal alteration have been investigated from two major geologic formations of the Damara Orogen (Namibia). The study sites are located in two distinct tectonostratigraphic zones with different tectonic and metamorphic histories. The Central Zone (CZ) is characterized by crustal-scale dome structures, extensive platform carbonates, numerous granitic intrusions, major shear zones and Karoo-age dolerite dike swarms.

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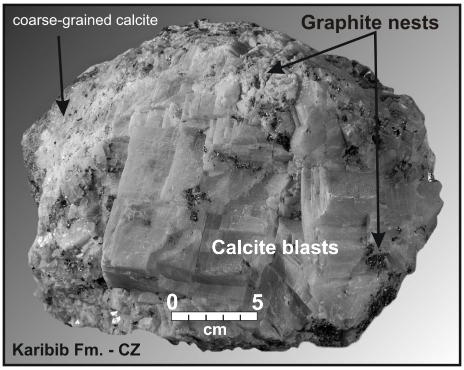

Figure 1: Large rhombohedral calcite blasts in a matrix of coarse-grained calcite with evenly distributed nests of graphite.

Amphibolite to granulite facies metamorphic conditions prevailed in the CZ. Shown in Figure 1 is a typical example of abnormal grain growth in a white graphite-bearing calcite marble of the Karibib Formation. Large rhombohedral calcite blasts are visible in a coarse-grained calcite matrix with graphite forming nests distributed throughout. Local lenses of grey calcite marble occur showing similar grain growth characteristics, but without graphite nests. Peak metamorphic temperatures in the graphite-bearing calcite reached 760° C (Walter 2004). Late-stage cataclastic and mylonitic deformation accompanied by hydrothermal alteration overprints the coarse-grained calcite marbles.

In the Southern Margin Zone (SMZ) where metadolomites of the Corona Formation were investigated, greenschist facies conditions prevailed with differences in style of deformation and hydrothermal alteration. Carbonates are differentiated into siliceous dolomites, talc-bearing dolomites, a dark dolomite mylonite and a medium-grained dolomite marble with large

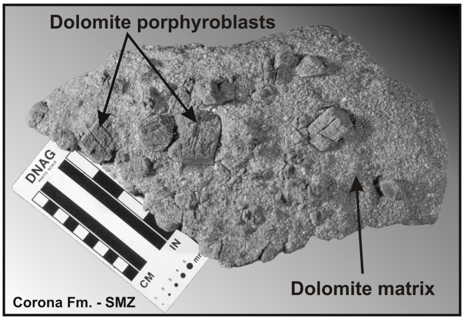

Figure 2: Metadolomite marble showing large dolomite porphyroblasts embedded in a matrix of medium-grained dolomite.

dolomite porphyroblasts (Fig. 2). Field evidence for extensive hydrothermal alteration is present as hydrothermal dolomite veins, hydrothermal quartz veins, extensive alteration in contact zones and bleaching of the dark dolomite mylonite.

Fabrics and microstructures

The graphite-bearing calcite marble of the CZ exhibits a wide variety of microstructures and fabrics. In the coarse-grained matrix domain, calcite shows irregular grain shapes characterized by serrated, interpenetrating grain boundaries. Some microstructural features include leftover grains, twin-free bulges migrating into neighboring grains and examples of relic triple-point grain boundaries undergoing transformation. Twinning occurs in varying degrees, with twin-boundary migration also observable. Contacts between matrix and blasts are curved and irregular. Thin flakes of graphite (3–4 mm in size) occur along grain contacts, in small clusters and occasionally in the large calcite blasts. Calc-silicate minerals occur in thin layers or clusters. When present in greater concentration, grain coarsening appears hindered.

In optical cathodoluminescence microscopy (CL), the coarse-grained calcite matrix and calcite blasts show homogeneous red CL colors with very low to medium luminescence. Calcite showing very bright luminescence occurs as cross-cutting micro-veins. The etch experiments reveal a qualitative map of dislocation densities. In the calcite marble etching occurred primarily along grain boundaries and formed trains of etch pits aligned parallel to twin boundaries.

The dolomite marble from the SMZ exhibits a somewhat granoblastic fabric with a visible shape-preferred orientation. The dolomite matrix grains range from flattened (a small percentage) to elongated in shape, where grain boundaries can be straight or show fine irregularities. Dolomite porphyroblasts appear anhedral in thin section. Relatively large numbers of very fine-grained inclusions of albite clusters, talc, quartz and pyrite are found in the dolomite porphyroblasts. The interface or contact zone between matrix and porphyblast is usually irregular and indentations of dolomite matrix grains into the porphyroblast are locally observable as well as leftover grains. Bulk neutron texture analysis revealed a moderate to strong crystallographic preferred orientation in the dolomite matrix.

The density of etch pits appears greater in the porphyroblast as compared to the matrix, with some etch grooves creating curved traces in the dolomite porphyroblast. SEM also revels relatively open grain boundaries in the matrix dolomite after etching.

Evidence for extensive grain-scale fluid-rock interaction is visible by CL in the dolomite marble. The CL color in un-

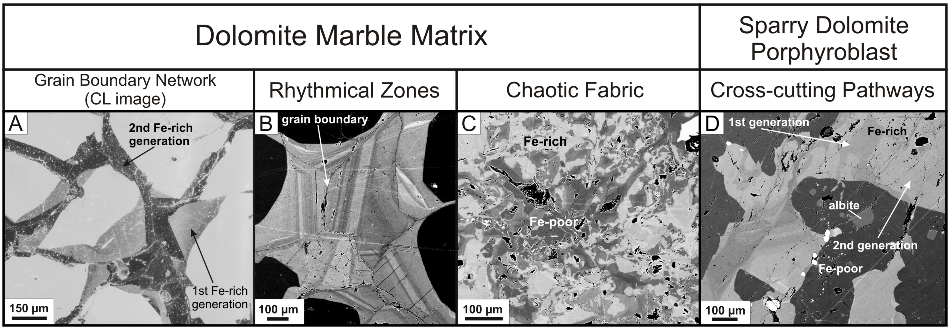

Figure 3: Classification of zonation types in the dolomite marble. A) CL image of the dolomite matrix depicting the two grain-boundary parallel Fe-rich zonations. B) Rhythmical growth zones indicating paleo-porosities. C) Local chaotic fabric of Fe-rich and Fe-poor dolomite. D) Fe-rich pathway (two generations) cut across the porphyroblast. Minor rhythmical zonations are also visible. Note: Pictures B-D represent back-scatter electron images.

altered matrix grains as well as in the pophyroblast is yellow-orange, whereas the Fe-rich areas exhibit various shades of brown. Figure 3 shows a classification of the types of zonation microstructures present in the matrix and porphyroblast. In the dolomite matrix an interconnected network of Fe-/Mn-rich zones, creating two distinct generations, occurs parallel the grain boundaries (Fig. 3A). Complex rhythmical zonations with alternating bands and sharp boundaries occur in some parts of the matrix (Fig. 3B). Chaotic CL fabric patterns occur locally and destroy the matrix grains and the grain-boundary zonations (Fig. 3C). In the dolomite pophyroblast (Fig. 3D), the Fe-rich alteration is represented by cross-cutting pathways also forming two generations. Furthermore, zoned albite clusters with dark cores and blue rims are always associated with the Fe-rich zonations. Those in the matrix are unzoned.

Discussion and conclusion

All the data indicates that the grain coarsening in the graphite-bearing calcite marbles is the result of regional metamorphism due to granitic intrusions (e.g. static recrystallization, Evans et al. 2001). The dominant mechanism responsible for the grain growth in the calcite marble is grain boundary migration, as is evident by the types of microstructures and fabrics observable in thin section.

Cathodoluminescence observations of the graphite-bearing calcite marble indicate that hydrothermal alteration was limited to a late-stage event. Microveins of brightly luminescent calcite (zoned and unzoned) are associated with the fluids accompanying cataclastic deformation and are not connected to the grain coarsening process. Fluid inclusions within the coarse calcite matrix and the calcite blasts have a composition similar to that of seawater. Fluids released by the granitic intrusions must have played a role in the coarsening process, since in theory the rate of grain growth and grain boundary mobility would be much slower under dry conditions.

The grain coarsening, porphyroblast growth and alteration in the dolomite marble is somewhat problematic. The dolomite porphyroblasts could be either younger or older than the coarsened matrix. The relic grain boundaries and possible leftover grains suggest the porphyroblast is younger, whereas embayments of matrix grains into the porphyroblast could suggest an older age. Furthermore, the grain coarsening and porphyroblast growth could have occurred earlier than the hydrothermal alteration, since the Fe-rich zones crosscut the porphyroblast. On the other hand, the CL zonations may represent evidence for fluid-enhanced grain coarsening and thus the mechanism of growth is solution/precipitation. Fluid inclusion data from dolomite veins point to highly saline solutions present during hydrothermal alteration.

The sequence of events for the hydrothermal alteration represented by the Fe-/Mn-rich zonation network can be separated out into five stages of a continuous process. Stage I introduces two Fe-/Mn-rich fluid generations. In Stage II intergranular pore spaces are created which are then filled in by rhythmically zoned dolomite (Stage III). Formation of a second generation of pore spaces occurs in Stage IV caused by corrosion of the original rock fabric. This leads to the precipitation of dolomite (Stage V) represented by the local chaotic CL fabric. All these events represent episodic fluid influxes possibly caused by seismic events, since the carbonate unit lies in close proximity to a thrust fault.

References

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Walter J (2004) Fabric development, electrical conductivity and graphite formation in graphite-bearing calcite marbles from the Central Damara Belt, Namibia. PhD Thesis, Georg-August University of Göttingen, pp 289