Stylolites and crack-seal veins in Finnmark, north Norway

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Sediments of the Cambro-Ordovician Digermul Group on Digermulhalvøya, north Norway, are locally deformed below the tectonically emplaced Caledonian Laksefjord Nappe. The rocks contain stylolite seams, crackseal veins, and conjugate shear surfaces, suggesting that deformation took place largely by pressure solution, local transport, and redeposition of quartz. An X : Z strain ratio of approximately 1.25 was achieved by this mechanism.

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In the valley Kistedalen on Digermulhalvøya, Finnmark, north Norway, the metamorphic Caledonian Laksefjord Nappe rests tectonically above folded but unmetamorphosed Cambro-Ordovician sediments of the Digermul Group (Reading 1965). The sediments of the Digermul Group are strongly altered within a zone up to 20 m below the basal Laksefjord thrust. The otherwise pale to dark sandstones and shales develop a dark charred appearance and a metallic surface sheen. At the same time a poor cleavage, subparallel to the Laksefjord thrust, is developed, and minor folds (with sub-horizontal axial surfaces and an axial trend of approximately 040°) become more numerous. Samples of these deformed rocks were taken, and one of these, a dark shale of the Kistedal formation (Reading 1975), showed various deformation textures, which are summarised here.

Textures

The sample discussed below was collected 3 m beneath the Laksefjord thrust. In hand specimen it is a dark fine-grained quartzitic rock with a black and gold metallic sheen. It contains a poorly developed elongate lensoid structure, and on the flanks of these lenses a rudimentary lineation is sometimes developed.

In thin section the sample is seen to be composed of polygonal quartz grains with a diameter in the order of 0.05 mm, with approximately 20% opaque minerals, clay minerals, and brown mica flakes distributed around the quartz grain boundaries. There is no dimensional preferred orientation of the quartz grains. Crossing the sample are conjugate planar shear surfaces, which give rise to the lensoid structure of the rock. Symmetrically disposed on the shear surfaces are a series of quartz veins, and, perpendicular to these, a series of stylolite seams (Fig. 1A).

Shear zones

The sample (Fig 1 B) is crossed by two conjugate sets of shear zones which intersect at 112 degrees. These shears give rise to the cleavage observed in the field. In thin section they appear as dark concentrations of opaque minerals, and sites for nucleation of brown mica. The concentration of opaque minerals is responsible for the metallic sheen seen on the shear surfaces. The shears occasionally decompose into stylolites and either a quartz vein or local irregular elongation of quartz grains. This decomposition may terminate the shear, or it may recombine after a short hiatus. The orientation of the shear surface is interesting in that shear fractures should theoretically be disposed so that their acute angel of intersection is bisected by the greatest compressive stress (Ramsay 1967: 289), whereas here the greatest compressive strain (as defined by the stylolites) bisects the obtuse angle. Possibly the shear surfaces developed by a difference mechanism, perhaps the modification of an already existing stylolite network.

Stylolites

Stylolites are defined by Park & Schot (1968) as 'Irregular planes of discontinuity ... commonly characterised by the concentration of relatively insoluble constituents of the enclosing rock "which" ... leaves no doubt as to their origin by the solution of material from one or usually both sides of the seam'. They have been described from rocks which have undergone Caledonide deformation in Troms, north Norway (Nicholson

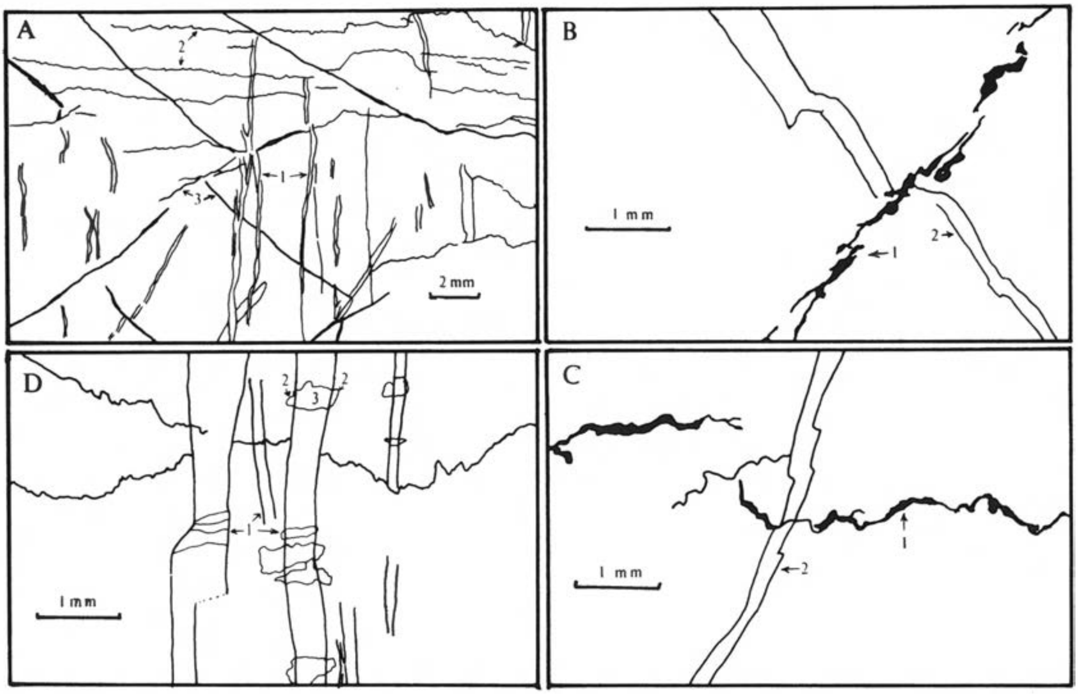

Fig. 1A. Tracing from a photomicrograph of the thin section, showing the arrangement of veins (arrowed '1'), stylolites (arrowed '2') and shear surfaces (arrowed '3'). The veins and stylolites are arranged perpendicular to each other, and are crossed by two conjugate sets of shear surfaces. B. A shear surface (1), shown by the build-up of opaque material, offsets a quartz vein (2). C. A stylolite (1), at which opaque minerals have accumulated as quartz has been removed, cuts across a quartz vein (2). D. A series of crack-seal veins (1) offset relic fragments of quartz grains (2) which are joined together by quartz in optical continuity (3).

1976), and have also been described in a Pre-Cambrian quartzite from Alberta (Conybeare 1949), so their appearance in a rock such as this is not entirely without precedent. The stylolites (Fig. 1C) are irregular surfaces with a complex wave-like shape in section, visible by the accumulation of opaque minerals along the stylolite seam. Quartz grains are truncated at the stylolite and are not seen to cross it. The irregular stylolite waveforms show three dominant wave-lengths. The most prominent wavelength is about 0.1 mm, i.e. with a half-wavelength similar to the diameter of the quartz grains. This may be a relic of the initial shape of the stylolite seam as it formed around the quartz grain boundaries. A shorter wavelength of about 0.03 mm is seen in the thinner stylolite seams, but is lost as the stylolites develop and thicken. This wavelength may be related to the grain size of the opaque minerals. A larger wavelength, about 1 mm, is also present. The stylolites form an anastomosing network symmetrical to, and at 34° from the shear surface.

Quartz veins

Perpendicular to the stylolites is a series of quartz veins (Fig. 1 D). These contain only quartz, the opaque minerals being confined to the rock either side. The 'crack-seal' mechanism of vein formation (Ramsay 1980) is one of fracturing of individual crystals within an aggregate, followed by separation of the broken parts and sealing of the vein by incoming material. Vein formation may proceed in a series of stages, and may be cyclic. When the vein material is a similar composition to the wall rock crystals, these crystals are sealed together by material in optical continuity.

It is proposed that the veins in the sample from Kistedalen originated by a rudimentary 'crack-seal' mechanism. In most of the veins, especially the smaller ones, the vein crystals are elongate quartz crystals often in perfect optical continuity with matching grain fragments in the rock matrix on either side. This makes the quartz veins hard to distinguish under crossed polars. They are recognised by the lack of opaque minerals and the clarity of the vein quartz. Successive positions of the vein centre are marked by trails of bubbles and inclusions, and many of the veins appear to have had polyphase growth histories. The number of phases, however, is perhaps too small and their magnitude too large for these veins to be identical to crack-seal veins of Ramsay's (1980) description. Rather better examples were observed in a specimen of a sandstone of the Vestertana Group (Reading 1965) in a similar tectonic situation below the Laksefjord thrust on Ifjordfjellet, about 35 km south west of Kistedalen, The veins in this sample are narrower than the grain diameter, and one grain may be crossed by several veins. This is in contrast to the Kistedalen sample, where the vein thickness is a similar size to the grain diameters. The sandstone shows no stylolites, however, or shear surfaces. If pressure solution took place, it must have been intergranular.

Relationships of minor structures

The cross cutting relationships of the veins, shears, and stylolites are complex. Veins are cut by some stylolites while themselves cutting others. Some veins which show polyphase growth histories are only cut by stylolites in their outer portions. Stylolites branch and merge, while shear zones may decompose into stylolites and veins. Shear surfaces offset some veins and are cut by others, and so on. The deformation history seems therefore to have been in detail complex, but in general a single episode involving simultaneous shear on conjugate surfaces, pressure solution on stylolitic seams, and redeposition of quartz in crack-seal veins is proposed.

Determination of strain

The minor structures were used in an attempt to determine the strain in a section cut perpendicular to the shear lens axes and parallel to the shear lineations. This section is also perpendicular to the quartz veins and the 'cleavage', so it is thought that this is an X : Z section.

The veins were measured to give a direct reading of extension parallel to X, an extension of 6.3% ± 0.5% being indicated. It was not possible to measure the extension in the sample from Ifjordfjellet, as it was difficult to distinguish the veins. However, an extension of greater than 5% was indicated. Contraction perpendicular to the stylolites was estimated by the build-up of opaque material on the stylolite seams. The build-up of a thickness of opaque material requires the removal by solution of four times as much quartz, as the opaque content of the rock is very close to 20%. Contraction parallel to Z as recorded by the stylolites is 5.9% ± 0.5%. The offset of veins across the shear zones suggests that an extension parallel to X of approximately 4.7% and a contraction parallel to Z of 3.7% has occurred due to shear since the initiation of the offset veins. The build-up of opaque material on the shear zones suggests a volume loss across them of approximately 1.4%.

Total extension in X is therefore 11% ± 1%
Total contraction in Z is therefore 11% ± 1%

There would seem to be little or no total volume loss in the system, and the deformation has occurred by local redistribution of quartz within the rock.

Conclusions

The deformation in the rock immediately below the Laksefjord thrust in Kistedalen has taken place largely through the transfer of quartz in solution. A strain ratio in the X : Z plane of approximately 1.25 has been developed by a combination of pressure, solution of quartz on stylolitic seams, redeposition of the quartz in crack-seal veins, and shear on conjugate shear surfaces.The deformation is probably a result of the emplacement of the Laksefjord Nappe, and may be due to high fluid pressures or high temperatures on the thrust fault making solutional deformation possible.

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