Is High Undulatory Extinction in Quartz Indicative of Alkali-Expansivity of Granitic Aggregates?

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ABSTRACT

Three granitic rocks were examined to evaluate the correlation between undulatory extinction (UE) in quartz and reactivity in concrete containing granitic aggregates. There appears to be moderate correlation between the measured UE angles and the observed rate of expansion of concrete. However, the presence of polygonisation in the quartz grains indicates that they are in a low energy state, hence they are probably not reactive. For this reason the correlation between UE angles and the rates of expansion of concrete may be fortuitous. Microcrystalline quartz that is known to be reactive occurs in the granite and granophyre, the most expansive aggregates. The observed reactivity of the granitic rocks can probably be correlated better with their microcrystalline quartz content.

INTRODUCTION

Some knowledge of the physical processes which cause undulatory extinction (UE) and the related phenomenon of polygonisation is necessary in order to understand the supposed correlation between the reactivity of quartz-bearing aggregates and high UE angles in quartz grains. White (1973) found by TEM examination of quartz grains showing high UE angles and polygonisation that deformation lamellae were associated with the formation and migration of dislocations in the quartz lattice. Figure 1a shows a portion of a quartz lattice to which a stress is applied. As the stress builds up, random dislocations are formed throughout the crystal. The energy of a dislocation is proportional to the work done in creating it, hence a crystal in this state would have a higher energy level and enhanced solubility, but no optical effects. As the stress increases further, particularly at high temperatures associated with tectonic processes, the dislocations migrate to form a wall (Fig. 1b). White (1973) found that numerous dislocation boundary walls are produced in a single deformed quartz grain. The optical effect of undulatory extinction is produced by successive misalignments at subgrain boundaries and the associated phenomenon of undulatory extinction is thus a recovery process; in this state the crystal has a lower energy level than in the state represented in Figure 1a. At a later stage in the recovery process, subgrain boundaries become large enough be visible in thin sections of quartz viewed in polarised light (Fig. 2).

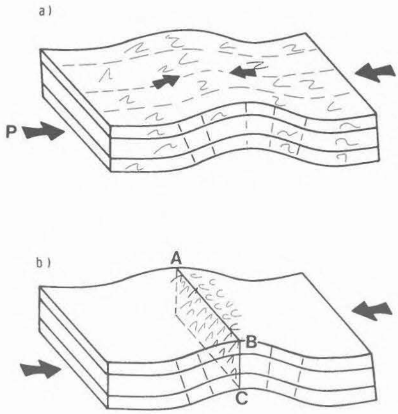


FIGURE 1
(a) Quartz lattice to which stress P is being applied. Small arrows indicate direction of movement of dislocations.
(b) Later stage in the recovery process from the applied stress. Dislocations have migrated to form a wall ABC.
-- random dislocations.

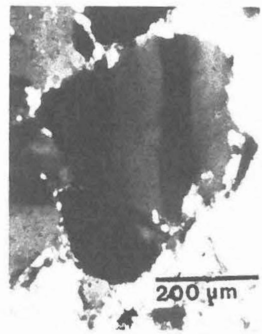


FIGURE 2
Optical micrograph, cross polarized light, showing subgrain boundaries in a large quartz grain.

The solubility of crystalline materials is increased by stress. It has been assumed that high undulatory extinction (UE) angles in quartz are a sign of stress in the lattice and increased solubility (reactivity) in alkaline solution (Gogte 1973, Mather 1976, Dolar-Mantuani 1981 and Buck 1983), but no rigorous proof of this hypothesis has been presented.

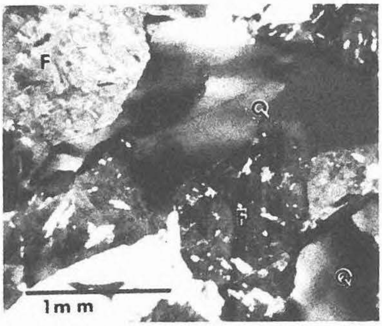
Most UE angle determinations have been made in quartzites or related rocks, which in addition to large quartz grains also contain microcrystalline quartz or chert, which may be the reactive component. Gogte (1973) reported on the reactivity of granites but the petrographic information provided is not sufficient to establish unequivocally the absence of microcrystalline quartz.

Granitic rocks generally do not contain microcrystalline quartz; hence three granitic rocks were examined to determine whether a correlation exists between alkali reactivity and high undulatory extinction in quartz. UE angles in quartz from the three granitic rocks were measured in thin sections. The expansion of concrete prisms made with the three rocks was also determined.

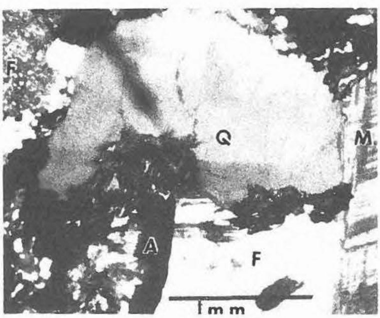
RESULTS AND DISCUSSION

Reactivity of microcrystalline quartz

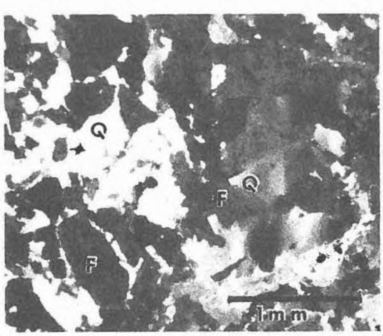
Microcrystalline quartz is a major component of novaculite and chert, rocks known to be reactive (McConnell et al 1947), but it has not been conclusively established that all microcrystalline quartz is reactive. Synthetic microcrystalline quartz was produced by grinding a quartz crystal to a size range of 4 to 40 µm. A solubility of 525 mMol/L was determined



(a) Granite



(b) Granodiorite



(c) Granophyre, showing typical micrographic quartz-feldspar intergrowth texture.

FIGURE 3
Optical micrographs of three granitic rocks. Q-quartz, F-feldspar, M-microcline, A-amphibole

for the synthetic microcrystalline quartz, indicating that it is reactive. UE angles of 20 to 30° were found in the crushed quartz but the reactivity cannot be uniquely correlated to the high UE angles, due to the presence of a defect layer on the surface of the quartz, a result of the grinding process; such defective quartz is known to be soluble.

Properties of the Granitic Rocks

Three granitic rocks were selected for determining the correlation between the reactivity of the rock and UE angles in the quartz. Experience has shown that many granites perform satisfactorily as aggregates in concrete; from this it may be concluded that the feldspars are non-reactive, despite some evidence that feldspars react with $Ca(OH)_2$ (Van Aart and Fisser 1977).

Granite: A grey granite from Barre, Vermont was selected on account of the high UE angle (40°) of its quartz grains. Figure 3 shows the appearance and grain size of the rock. The composition is given in Table 1. Careful examination in the petrographic microscope at high magnification revealed the presence of microcrystalline quartz around the boundaries of some grains (Fig. 4). It has a grain size of 10 to 20 μm.

Granodiorite: The grain size of this rock lies in the range of 0.5 to 1.2 mm (Fig. 3b). A mean UE angle of 19.5 ± 5° was measured in the quartz. About 75% of the large quartz grains are polygonised and exhibit narrow subgrain boundaries. Microcrystalline quartz was not observed.

Granophyre: The mean grain size is 0.6 mm (Fig. 3c). A mean UE angle of 35 ± 11° was measured in the quartz. Most quartz grains show a high degree of polygonisation. Occasional grains of microcrystalline quartz were observed but they are less common here than in the granite.

Expansion of Concrete Prisms

Concrete test prisms were made with the three rocks and a cement

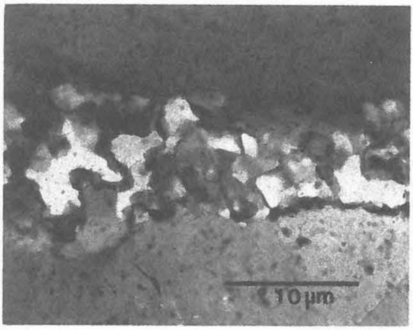


FIGURE 4
Microcrystalline quartz between two large quartz grains.

with an alkali content of 1.08% Na_2O equivalent. They were stored at 38°C and 100% humidity. The expansion of the prisms is shown in Figure 5.

Figure 6 shows the UE angle in quartz versus the expansion of concrete prisms containing the three granitic rocks. An estimate of the percentage of microcrystalline quartz in the rocks is also plotted on the abscissa of Figure 6. The correlation between the UE angles in the quartz and the expansion of concrete prisms made with the three granitic rocks appears to be moderately good. However, the expansion of the concrete may be due to microcrystalline quartz. UE angles measured in this study following the method of DeHills and

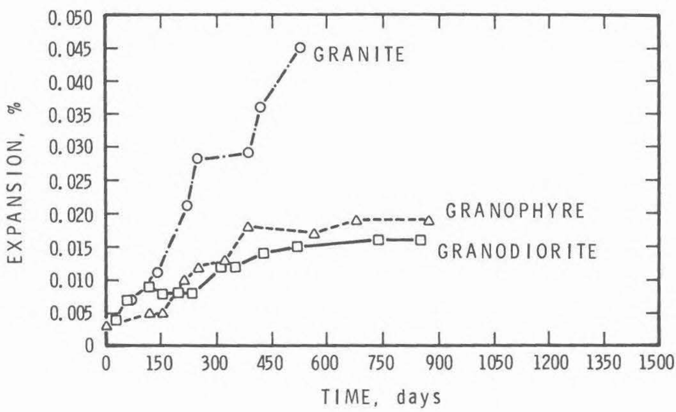


FIGURE 5
Expansion of concrete prisms stored at 38°C and 100% humidity, with time.

Corvalan (1964) are about 5° higher than angles measured using the method of Dolar-Mantuani (1981), who proposed that UE angles of less than 15° indicate non-reactive quartz; accordingly this figure should probably be increased to 20°.

Quartz in granodiorite with a UE angle of 19.5° would be classed as marginally reactive. The quartz in the granophyre, with a UE angle of 35°, and that in the granite, with a UE angle of 40°, would be classed as reactive. Only the concrete containing granite is deleteriously expansive, but this rock contains microcrystalline quartz. Due to the well known pessimum effect (Hobbs 1978), even the small amount of microcrystalline quartz present in the granite could account for the expansivity of the concrete. In conclusion, no definite evidence of a correlation between high UE angles in quartz in granitic rocks and the expansion of concrete containing them was found. The observed expansion of the concrete probably correlates, rather, with the microcrystalline quartz content of the rocks.

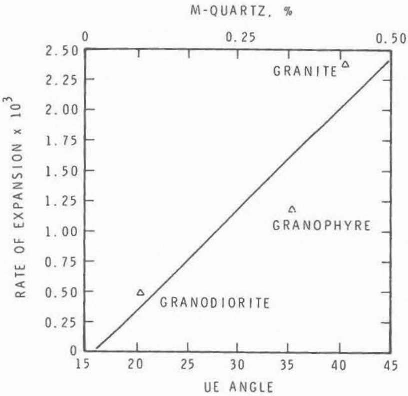


FIGURE 6
Graph of undulatory extinction (UE) angles in quartz from three granitic rocks versus rate of expansion of concrete containing them. An estimate of the amount of microcrystalline quartz (M-QUARTZ) is also shown.

ACKNOWLEDGEMENT

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TABLE 1

Mineralogical composition of three granitic aggregates. Second section shows undulatory extinction in quartz, percentage of microcrystalline quartz in the aggregates, and rate of expansion of concrete prisms made with the three aggregates and high alkali cement, stored at 38°C and 100% RH.

MINERALS	GRANITE %	GRANODIORITE %	GRANOPHYRE %
Quartz	17.5	17.4	28.0
Alk. Feldspar	68.0	58.6	40.0
Microcline	3.6	-	-
Hornblende	0.6	8.9	6.0
Biotite	8.5	0.1	-
Pyroxene	-	-	4.0
Chlorite	-	7.4	8.0
Epidote	-	3.1	3.0
Accessory Minerals	1.7	4.5	1.0
TOTALS	99.9	100.0	100.0
Undulatory Extinction in Quartz	40°	19.5°	35°
Micro-Crystalline Quartz %	≃0.5	0	<0.5
Rate of Expansion of Concrete Prisms × 10^{-3}	2.4	0.5	1.2