Quartz Inversions and Conversions

Crystalline solids are rather temperamental and quartz is no different. Quartz is a crystalline form of silica in that it has a three dimensional regular pattern of molecular units. These form naturally in nature because lengthy cooling times allow arrangement. Quartz is made of a network of triangular pyramid (tetrahedron) shaped molecules of silicon combined with four oxygens. Unfortunately, the quartz delights in changing the orientation of the tetrahedron shaped molecules with respect to each other, thus loosening or tightening the whole mass (and thus changing its total size). It exhibits twenty or more personalities called "phases" and these show a remarkable range of physical properties. A change to another phase is called a "silica conversion". The most significant phases are quartz, tridymite, crystobalite, and glass. The material does not even [need to] melt to change phase (except to produce silica glass of course). Only an elevated temperature to increase molecular mobility along with the required time is needed. What is more, each of the above crystal phases has two or more forms (alpha and beta, beta one, etc.). Changes which occur between these are reversible, that is, the change which occurs during heat-up is inverted during cool down. These changes are thus called "quartz inversions". These inversions, unfortunately, often have associated, rather sudden, volume changes. That means that quartz conversions are something to consider when optimizing the fired properties; quartz inversions are something to consider when firing to prevent cracking losses.

There are two important inversions you need to know about because of their sudden occurrence during temperature increase and decrease. The first is simply called 'quartz inversion' and it occurs quite quickly in the 570°C range (1060°F). In this case, the crystal lattice straightens itself out slightly, thus expanding 1% or so. The second is crystobalite inversion at 226°C. This is a little more nasty because it generates a sudden change of 2.5% in volume and it occurs at a temperature within the range of a normal oven. This material has many more forms than quartz, so it is a complex animal to say the least. However, while all bodies will have some quartz, you won't have a problem with crystobalite inversion unless there is crystobalite in your body. Crystobalite forms naturally and slowly during cooling from above cone 3. It forms much better if pure crystobalite is added to the body to seed the crystals or in the presence of catalysts (e.g. talc in earthenware bodies).

You can ignore these phases. But you will never be able to fully optimize fired properties of your ware and will never fully address "inversion" related firing problems without at least a partial knowledge of silica phases. We could just melt quartz, cool it quickly, and the resulting glass (irregular arrangements of molecules) could be ground into a powder having very stable firing behavior. This would really make things much simpler. Unfortunately, silica melts at a very high temperature, so this is impossible. So we have to live with the stuff and learn to cooperate with it during the firing process.

As noted already, individual particles of quartz in the body change from alpha to beta form of the quartz phase and back during heat up and cool down. It is important to realize that it is not the whole piece of ware, or even the silica within it, that undergoes the associated volume change. It is the small and even microscopic particles of the quartz that do. This behavior is, of course, dampened by the structure in which they exist. During heat up, these particles are in a non-glass bound matrix surrounded by other particles and pore space, so there is much tolerance for the volume change associated with the inversion. However, during cool down or subsequent heat ups, where the clay matrix is a solid mass of glass melted around each particle of quartz, sudden volume changes in the quartz particles are much more likely to cause micro cracks radiating around each. Since the quartz can form the skeleton of the entire structure, waves of change

occur through a piece which tend to extend the micro cracks into major cracks.

What does this all mean? It means there is not too much to worry about with quartz inversion in first fire ware on the way up, or about cool-down for bisque ware. In both cases, the open body is quite tolerant. However, take it easy on second-fire earthenware, very easy on second-fire stoneware, and super easy on second-fire porcelain. Watch for excessive amounts of quartz powder in dense bodies that do not fire to full vitrification. In these, the quartz has not been dissolved by the corrosive action of the fluxes, but remains part of a non-homogenous fired matrix. If possible, use the finest quartz powder available and this will make dunting (cooling cracks) during firing less of a problem.