Measuring stress and strain in rocks by spectroscopy

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Microstructures and the different thermoelastic properties of minerals ensure that no rock is ever under perfect hydrostatic stress at the grain level. If deviatoric stresses and strains significantly modify thermodynamic properties of minerals so that the equilibrium assemblage and compositions are different from that predicted from hydrostatic conditions, it is crucial to be able to measure the stress state of minerals in-situ in rocks. Forty years ago it was considered that ‘Analysis of residual stresses at the scale of mineral grains within a polycrystalline aggregate such as a rock is virtually intractable’ [1]. This is no longer true.

Confocal Raman spectroscopy allows spectra to be collected from small volumes of mineral grains within a section. The positions of Raman peaks depends on the elastic strains in the minerals through the phonon-mode Grüneisen tensors [2]. The development of precise DFT simulations of crystal structures and their Raman spectra now allows the components of the phonon-mode Grüneisen tensors to be calculated [3]. With these tensors it is possible to determine the strains from measured Raman peak positions, to thereby map the strain, and hence the stress state, of individual mineral grains. We have now extended the DFT simulations to show that the Raman shifts of crystals subject to symmetry-breaking stresses (e.g. around inclusions) are, as expected, not solely determined by the phonon-mode Grüneisen tensors of the ideal crystal. We have also recently developed the measurement of the change in peak intensities in cross-polarised Raman spectra to determine the stress [4] in these cases. For minerals such as garnets, this effect is stronger and therefore more sensitive to stress than the shifts in peak positions and offers at the moment the possibility to quickly visualise stress and strain fields in minerals in-situ in rocks.

Quantitative stress values from this method await the determination of the piezo-phonon tensors for garnets, but comparison of peak positions and intensities show that the two methods return consistent results.

This work was supported by ERC-StG TRUE DEPTHS grant (number 714936) to M. Alvaro. N. Campomenosi was also supported by the University of Genova.