ROSE
ROck SEismic research project

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Study on the stress dependency of elastic and non-elastic processes in a dry sandstone

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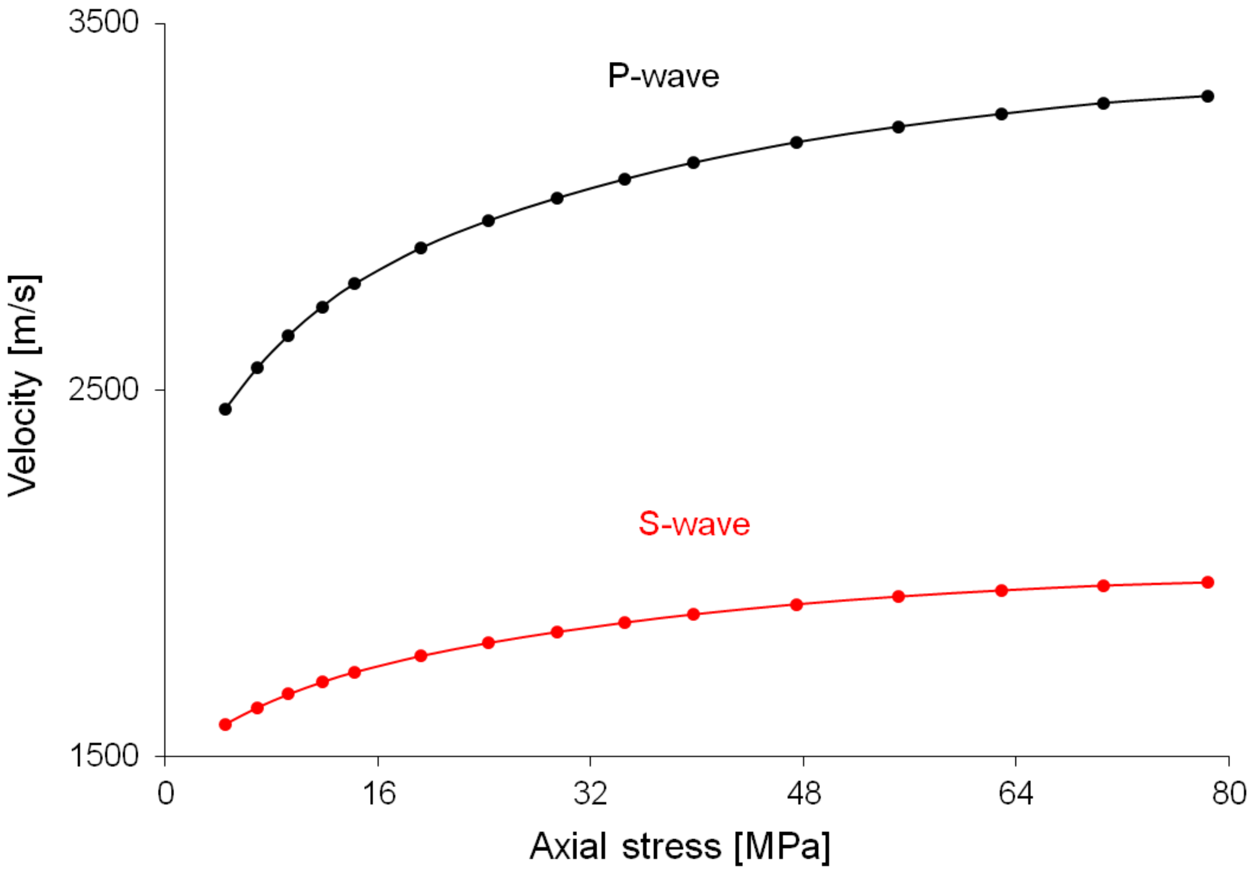
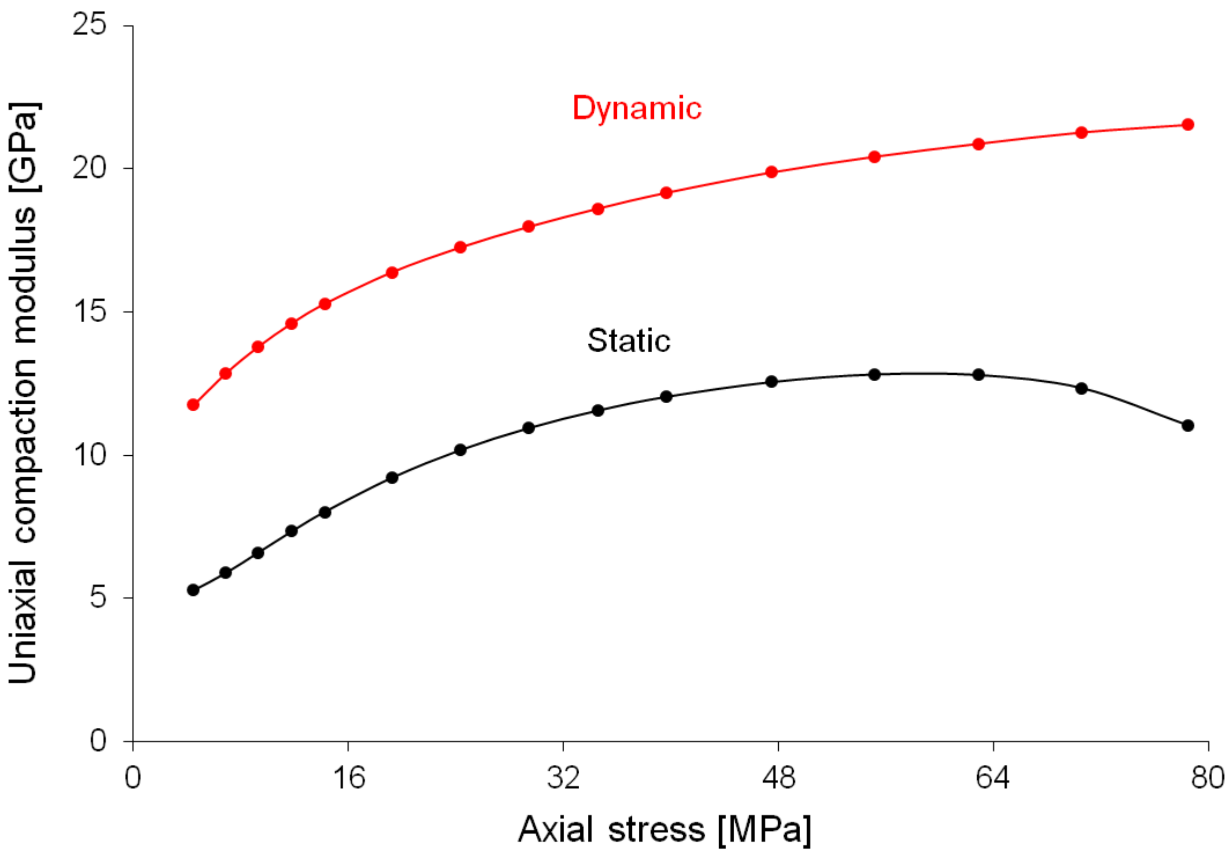
Causes for the stress-sensitivity of wave velocity in sandstone



Separate elastic and non-elastic processes activated in the rock structure under stress

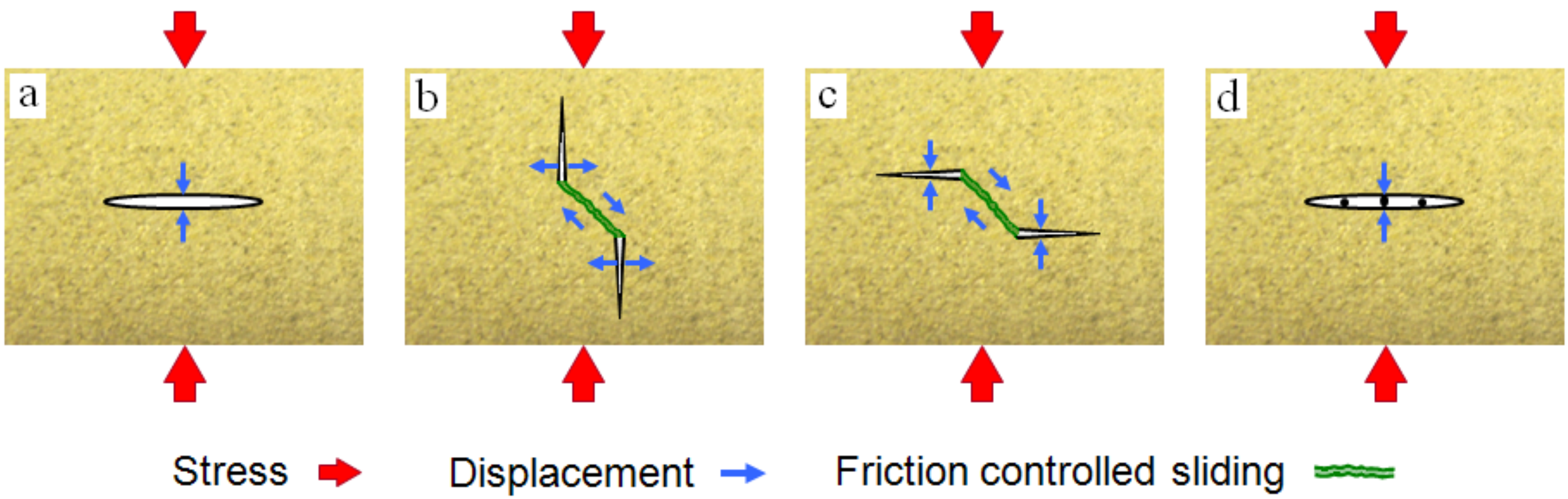
Difference between static and dynamic modulus



Difference can be explained to the processes activated in the rock structure under stress

Processes activated in the rock framework under stress (idealized examples):

- **Elastic processes**
  - Closing/opening of cracks (Fig. a)
- **Non-elastic processes**
  - Friction controlled shear sliding of internal surfaces in contact resulting in e.g. opening/closing of wing-cracks (Fig. b, c)
  - Crushing of asperities at grain contacts or crack faces (Fig. d) - only during loading



Mechanic system:

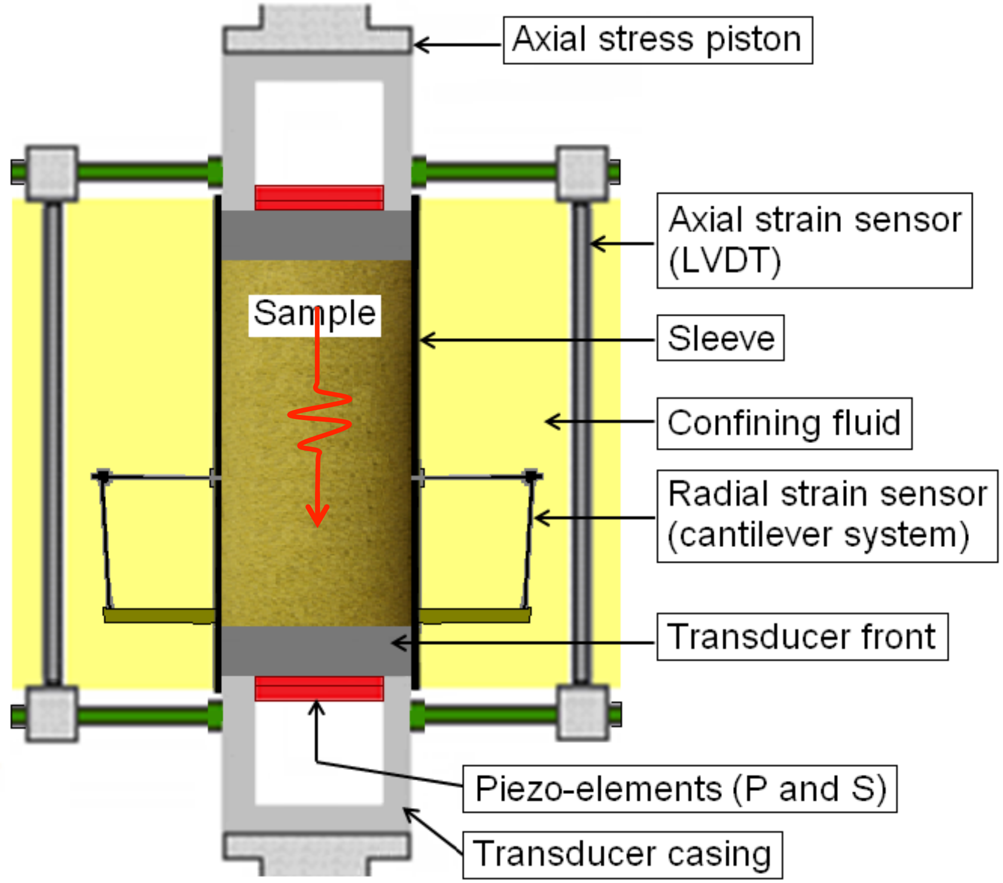
Triaxial cell (MessTek)

- Axial and radial stress
- Axial and radial strain

Acoustic system:

Ultrasonic transducer

- Single-sine pulse
- Frequency 500 kHz
- P- and S-wave
- Waves propagate along the major external stress i.e. axial stress



Scheme of experimental system

Samples:

- Four rock samples have been tested
- Two samples of Castlegate sandstone and two of Berea sandstone

Castlegate sandstone

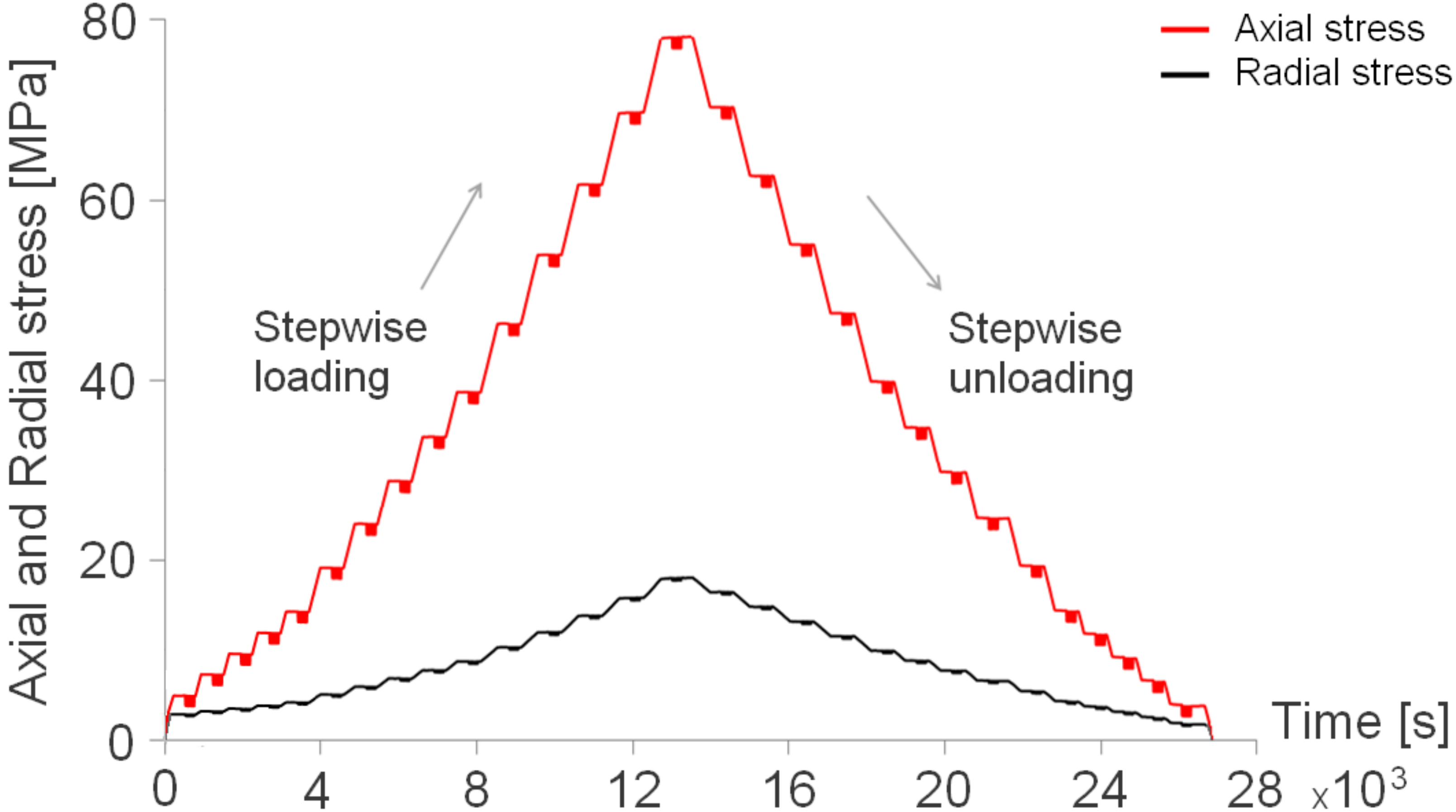
- Composition: 70% quartz, 30% feldspar and other rock fragments
- No clay
- Porosity ~ 26%

Berea sandstone

- Composition: 80% quartz, 12% feldspar and other rock fragments
- Clay ~ 8%
- Porosity ~ 19%

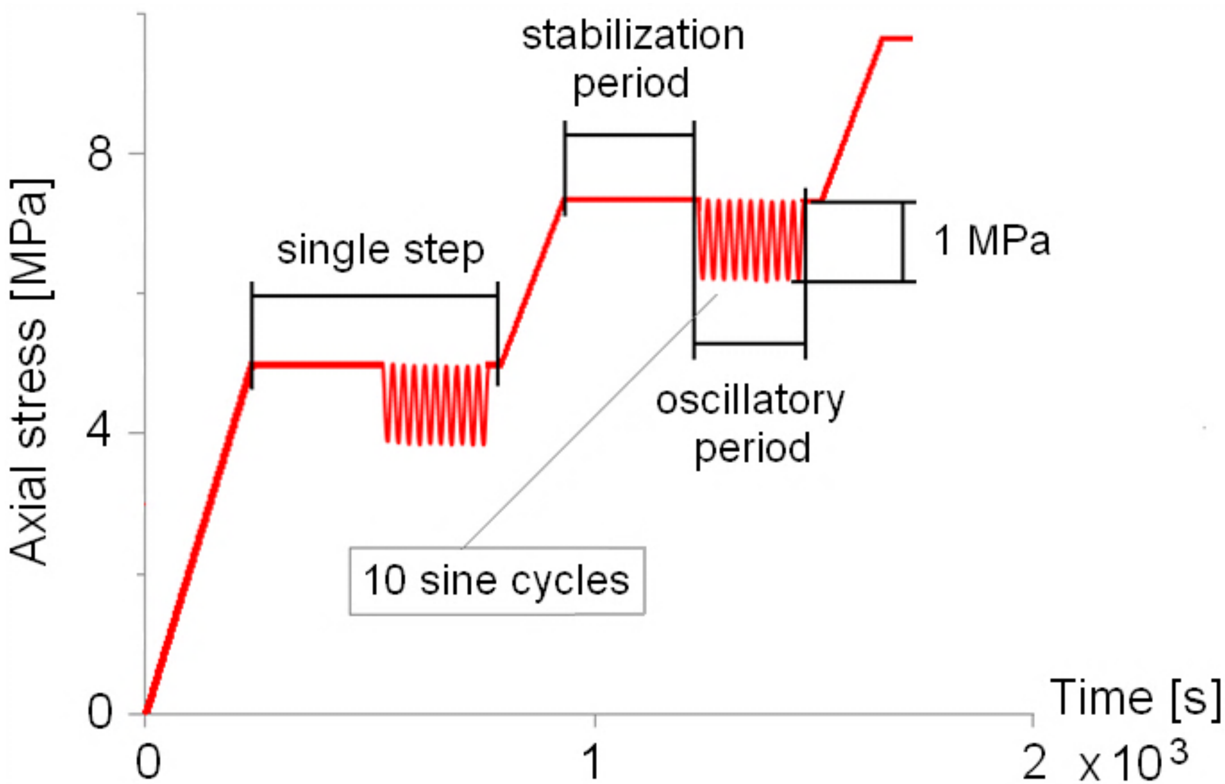
- All samples were dry
- Samples prepared as cylindrical plugs, size about 1.5''/3'' (diameter/length)

Stress path



- Uniaxial compaction (K_0 mode) test
- Stepwise stress change
- Loading and unloading paths repeated twice

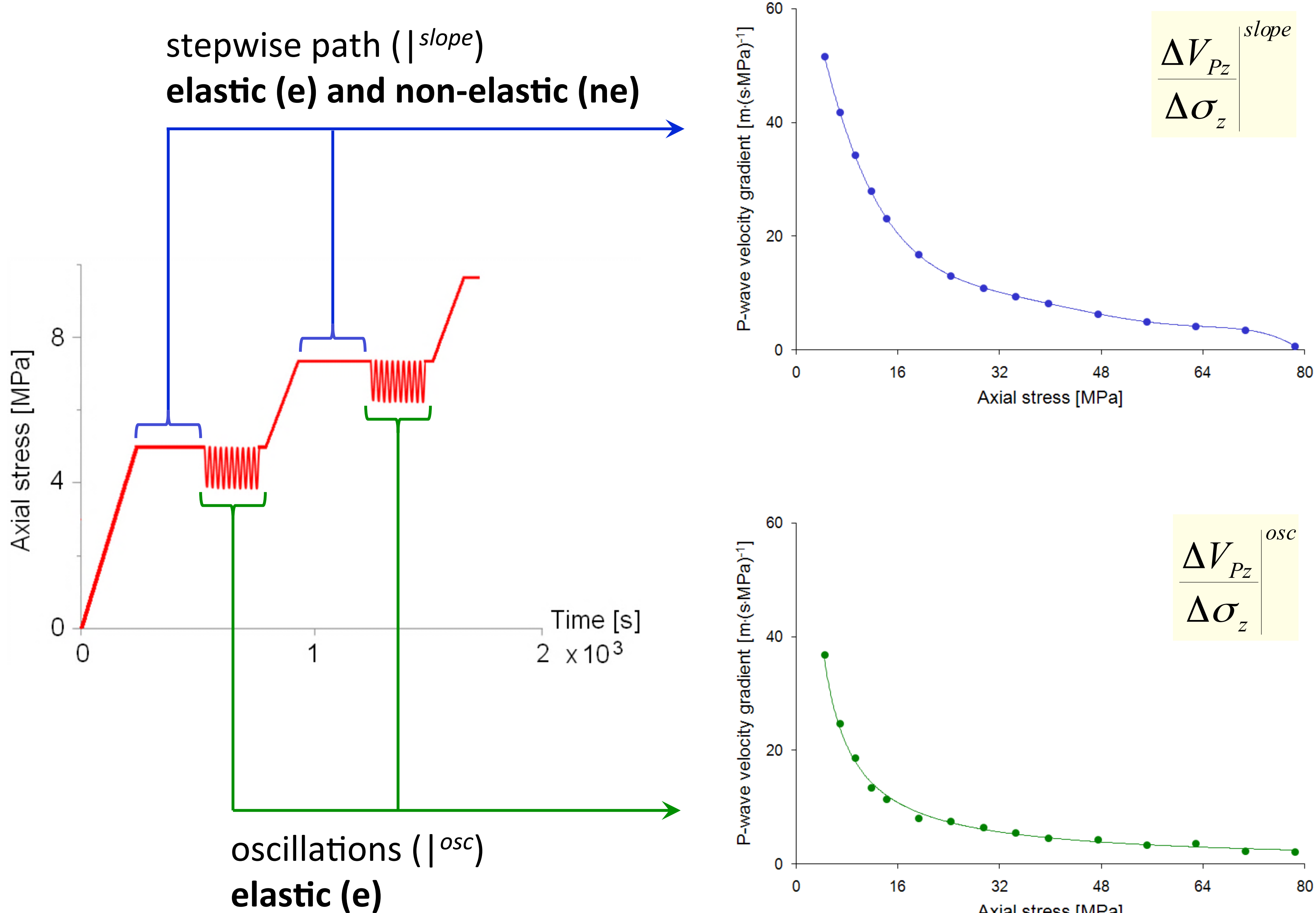
Stress path details



Stepwise path due to large-scale stress changes includes information about the elastic and non-elastic effects

Oscillatory periods that represent small-scale stress changes reveals information about the elastic effects only

Velocity response on stress path

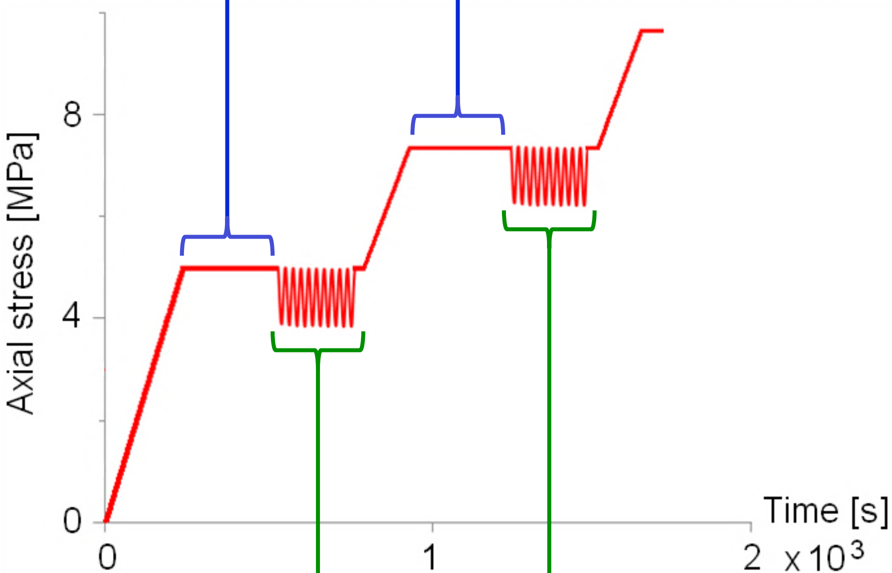


stepwise path ($|^{slope}$)

elastic (e) and non-elastic (ne)

$$\left.\frac{\Delta C_{33}}{\Delta\sigma_z}\right|^{slope} = \frac{\Delta C_{33}^{e}}{\Delta\sigma_z} + \frac{\Delta C_{33}^{ne}}{\Delta\sigma_z} =$$

$$= 2\cdot\rho\cdot V_{Pz}\cdot\left.\frac{\Delta V_{Pz}}{\Delta\sigma_z}\right|^{slope} + V_{Pz}^{2}\cdot\left.\frac{\Delta\rho}{\Delta\sigma_z}\right|^{slope}$$



$$\boxed{\frac{\Delta C_{33}^{ne}}{\Delta\sigma_z} = \left.\frac{\Delta C_{33}}{\Delta\sigma_z}\right|^{slope} - \left.\frac{\Delta C_{33}}{\Delta\sigma_z}\right|^{osc}}$$

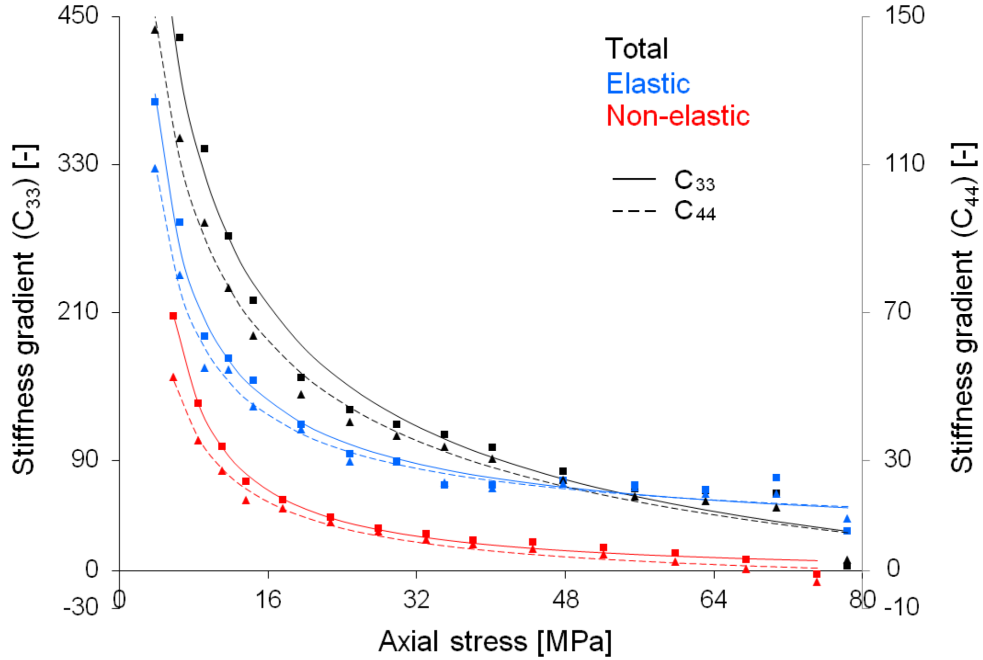
$$\left.\frac{\Delta C_{33}}{\Delta\sigma_z}\right|^{osc} = \frac{\Delta C_{33}^{e}}{\Delta\sigma_z} =$$

$$= 2\cdot\rho\cdot V_{Pz}\cdot\left.\frac{\Delta V_{Pz}}{\Delta\sigma_z}\right|^{osc} + V_{Pz}^{2}\cdot\left.\frac{\Delta\rho}{\Delta\sigma_z}\right|^{osc}$$

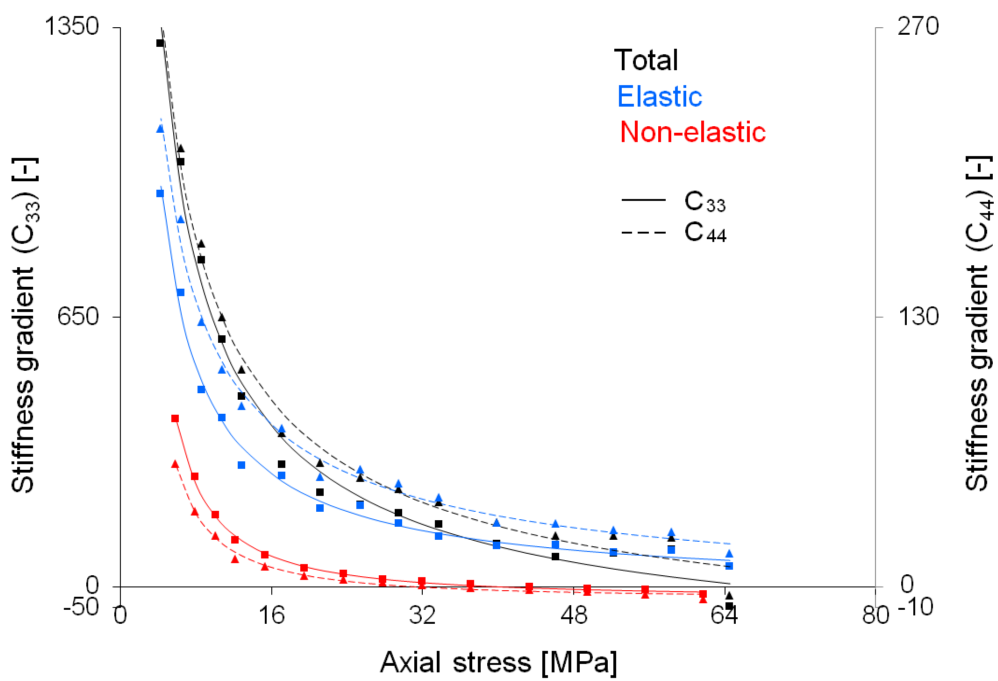
oscillations ($|^{osc}$)

elastic (e)

Castlegate sandstone



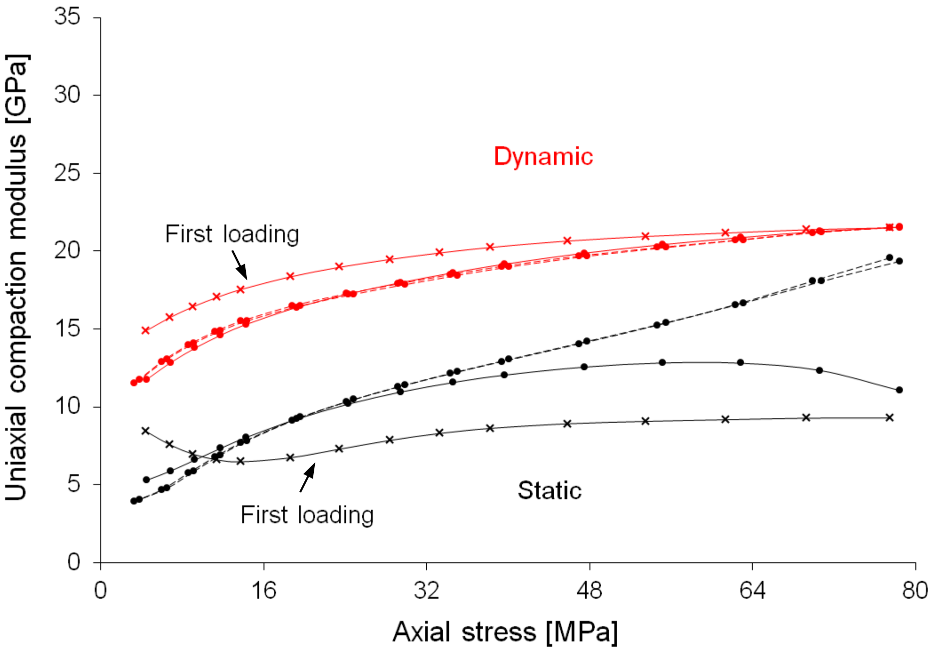
Berea sandstone



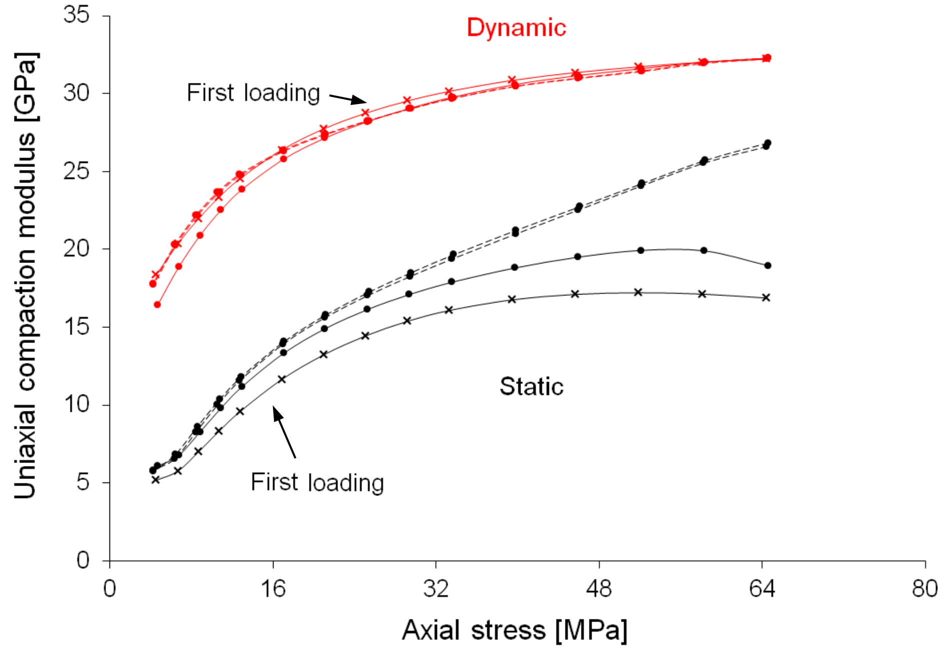
Uniaxial compaction

$$C_{33}\big|^{static} \neq C_{33}\big|^{dynamic}$$

Castlegate sandstone



Berea sandstone



$$C_{33}\big|^{static} = \frac{\Delta\sigma_z}{\Delta\varepsilon_z} = C_{33}^{ne} + C_{33}^{e}$$

Static modulus
elastic (*e*) & non-elastic (*ne*) processes

$$C_{33}\big|^{dynamic} = \rho \cdot V_{Pz}^2 = C_{33}^{e}$$

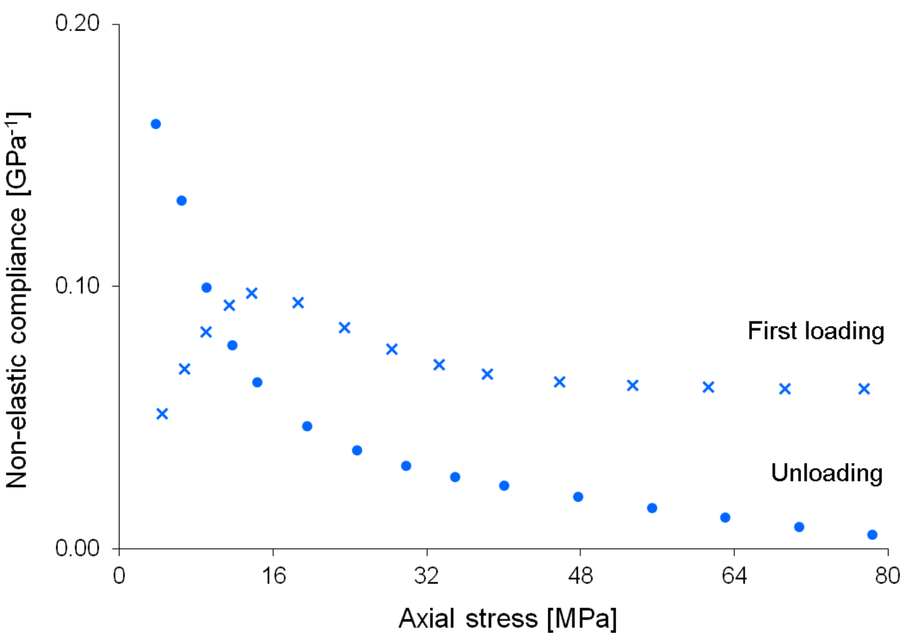
Dynamic modulus
elastic (*e*) processes only

Uniaxial compaction $\left.C_{33}\right|^{static} \neq \left.C_{33}\right|^{dynamic}$ because $C_{33}^{ne} + C_{33}^{e} \neq C_{33}^{e}$

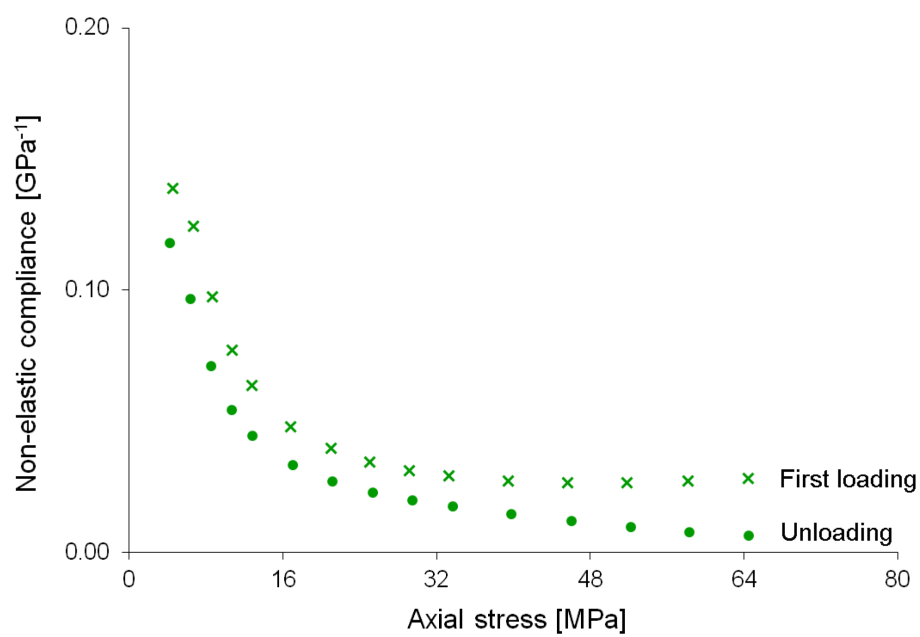
The non-elastic compliance component S_H^{ne}

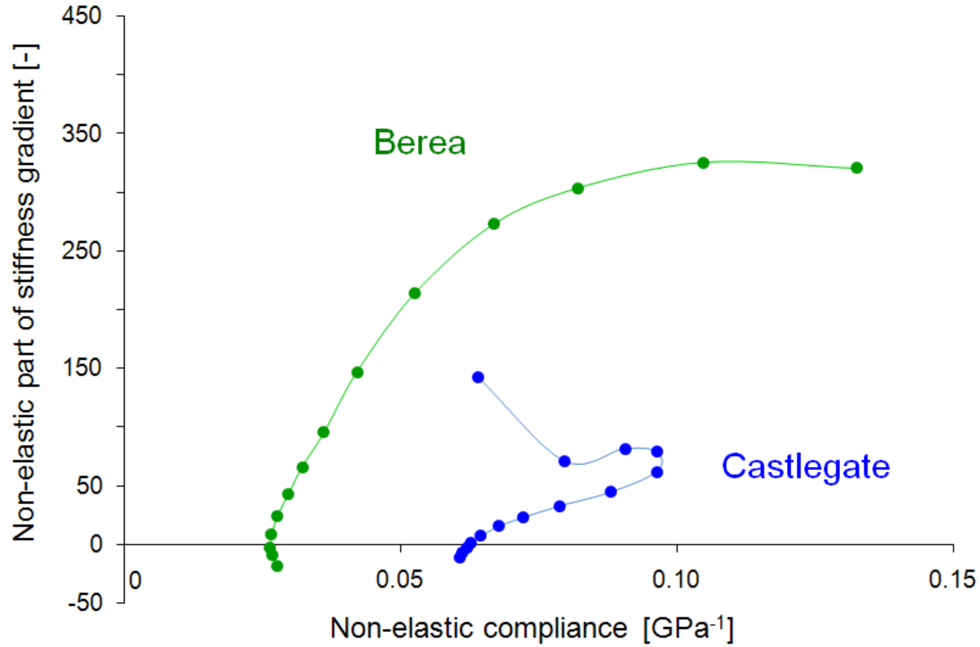
$$S_H^{ne} = \frac{1}{\left.C_{33}\right|^{static}} - \frac{1}{\left.C_{33}\right|^{dynamic}}$$

Castlegate sandstone

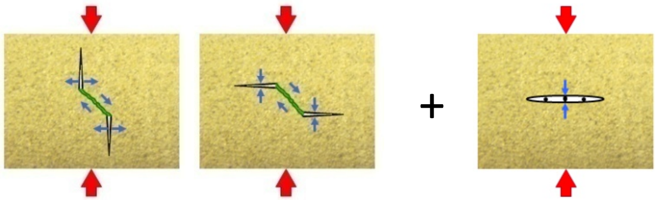


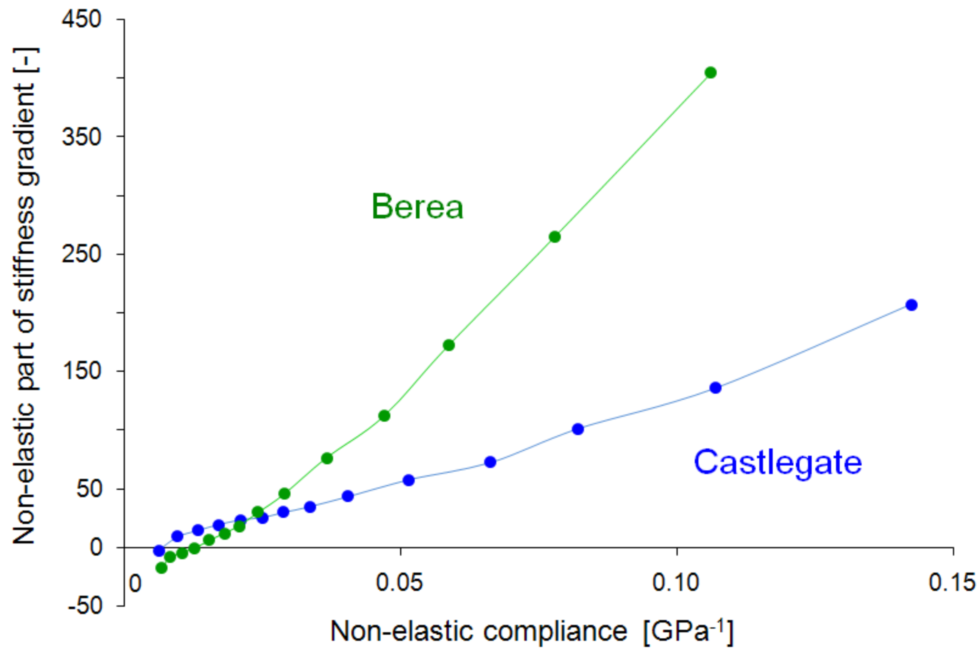
Berea sandstone



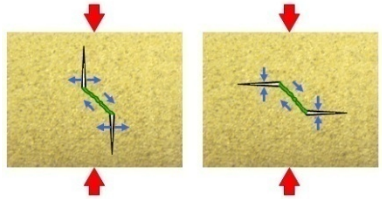


First loading





Unloading



Conclusions

- The stress-dependence of elastic waves is caused mainly by an elastic process, however the non-elastic processes become increasingly important at higher stress levels

- The difference between the static and the dynamic uniaxial compaction modulus can be ascribed to the same type of non-elastic effect during unloading

- Castlegate and Berea sandstone show significantly different stress-sensitivity, which may be associated with structural differences

Acknowledgments

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