The effects of impure CO_2 on reservoir sandstones: results from mineralogical and geomechanical experiments

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COORAL

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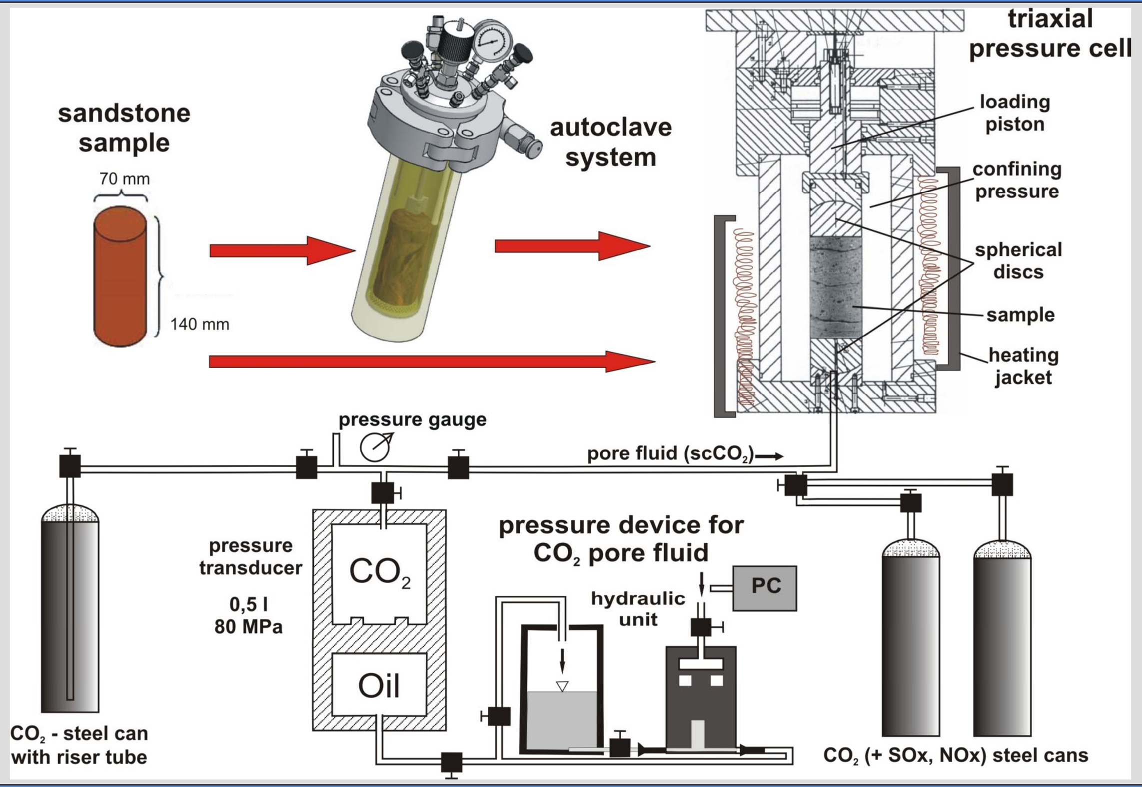

Fig. 1: The experimental flow: sandstone samples were controlled altered in a autoclave system (with brine + $scCO_2$ + NO_X + SO_X under 100°C and 100 bar, 2-4 weeks) and then loaded in a heatable triaxial pressure cell (under 50°C to 80°C and up to 30 MPa confining pressure, 25 MPa pore fluid pressure and a maximum of 107 MPa axial pressure) with CO_2 + up to 500 ppm NO_X and up to 1000 ppm SO_X as pore fluid. Also untreated samples were tested in the triaxial cell.

Project and Methodology:

Within the German project COORAL* the behaviour of potential reservoir rocks during the injection and geological storage of CO_2 with inherent impurities such as SO_X and NO_X is studied in laboratory experiments. A combination of geochemical and geomechanical studies are performed as autoclave experiments and subsequent tests in a triaxial pressure cell with dry and brine saturated sandstone samples. For a comparative study controlled altered rock samples (with supercritical (sc)CO_2 + SO_X + NO_X in an autoclave system) were loaded in a triaxial pressure cell under in-situ PT-conditions (Fig. 1), to study changes of the mineralogical, geochemical and geomechanical rock properties. Working materials are sandstones of possible reservoir formations of the North German Basin (Fig. 2).

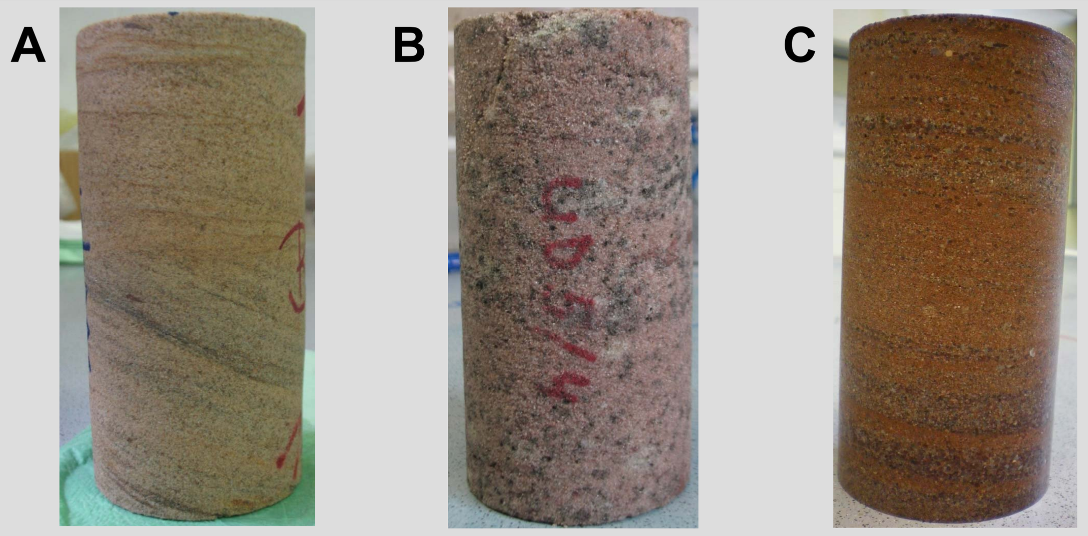

Fig. 2: Three types of sandstones from the North German Basin (samples with Ø=70 mm, L=140 mm):
A: Silicate sandstone "Mid Bunter Sandstone" (lower Triassic; porosity: ~ 22 %)
B: Carbonate sandstone "Mid Bunter Sandstone" (lower Triassic; poro.: ~ 16%)
C: Silicate and carbon. "Rotliegend sandstone" (lower Permian; porosity: ~ 8 %)

Results:

- **Silicate Bunter sandstone samples show decreased rock strength under enhanced pore fluid pressure (from 60% to 80% σ_3; Fig. 3 A).**
- **A clear dependency of chemical fluid composition and confining pressure (lithostatic) on the maximum differential stress (effective stress) especially on carbonate sandstones (Fig. 3 B) is obvious according to the experimental results.**

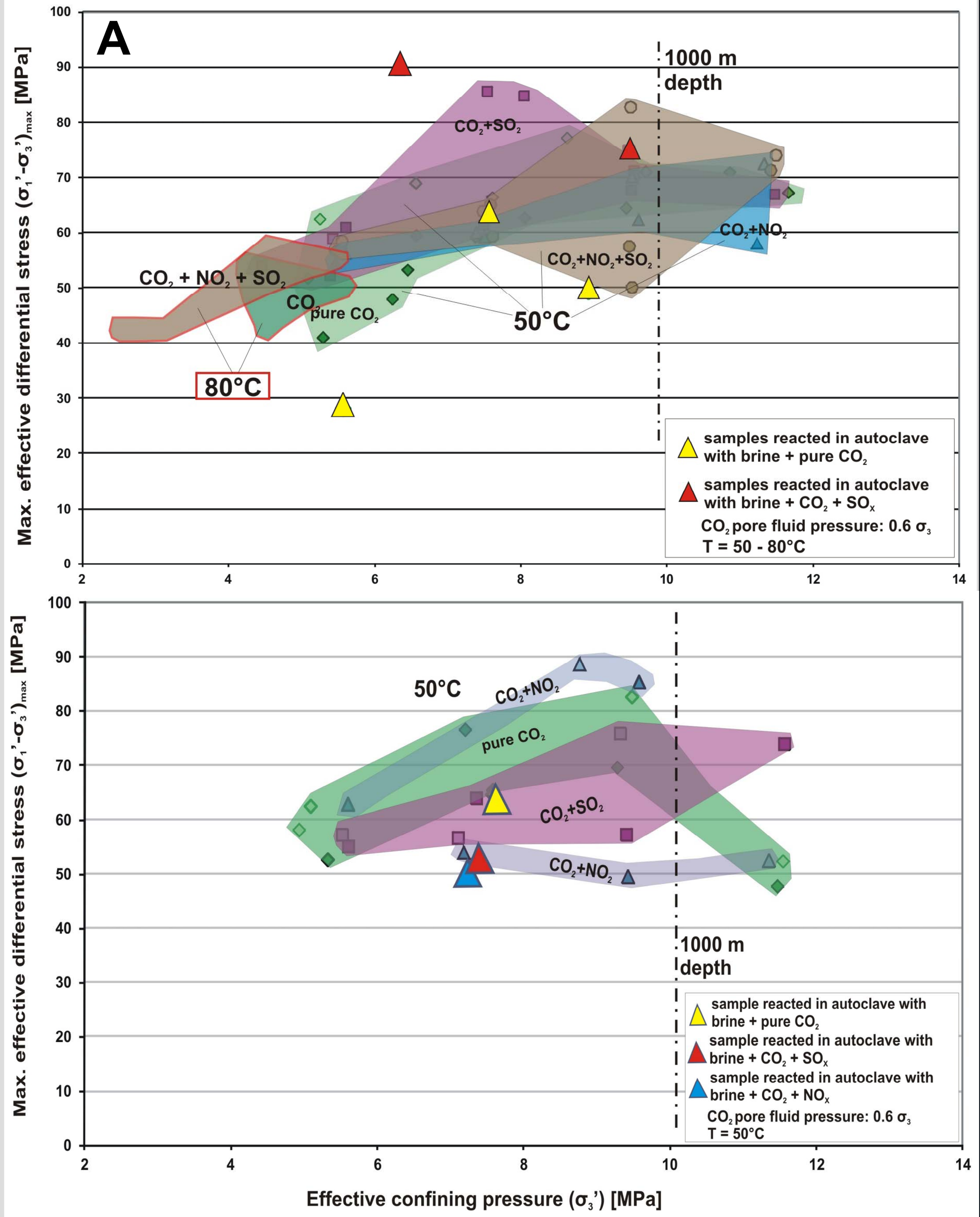

Fig. 3: Differencial stress diagrams showing the influence of rock saturation, confining pressure (σ_3), pore fluid composition (CO_2 with SOx and NOx) and pore fluid pressure (p) on the maximum effective stress σ_1'- σ_3' (σ_1'= σ_1 - p; effective confining pressure σ_3' = σ_3 - p) for silicatic (**A**) and carbonatic bound (**B**) Bunter sandstones. The differently coloured polygons connect sample points of equally pore fluid chemistry. A total confining pressure of 25 MPa corresponding 1000 m reservoir depth.

- **Contents of dissolved metals in the reaction fluid during the autoclave alteration experiment depends on the impurities (SO_X and NO_X) in the CO_2 gas stream (Fig. 5 A).**
- **Dissolution rates (Fig. 5 B) of bulk rock (sandstones) as well of single minerals varies with the carbonate fraction. Rates are calculated according to the formula:**

$$r = \frac{dm_i}{d_t} \cdot \frac{V}{A_s \cdot M_s}$$

r : dissolution rate (mol m^{-2} s^{-1})
A_s: inner surface (BET) (m^2/g)
m_i: molar concentration
t : time (s)
V : fluid volume (l)
M_s: mass (g)

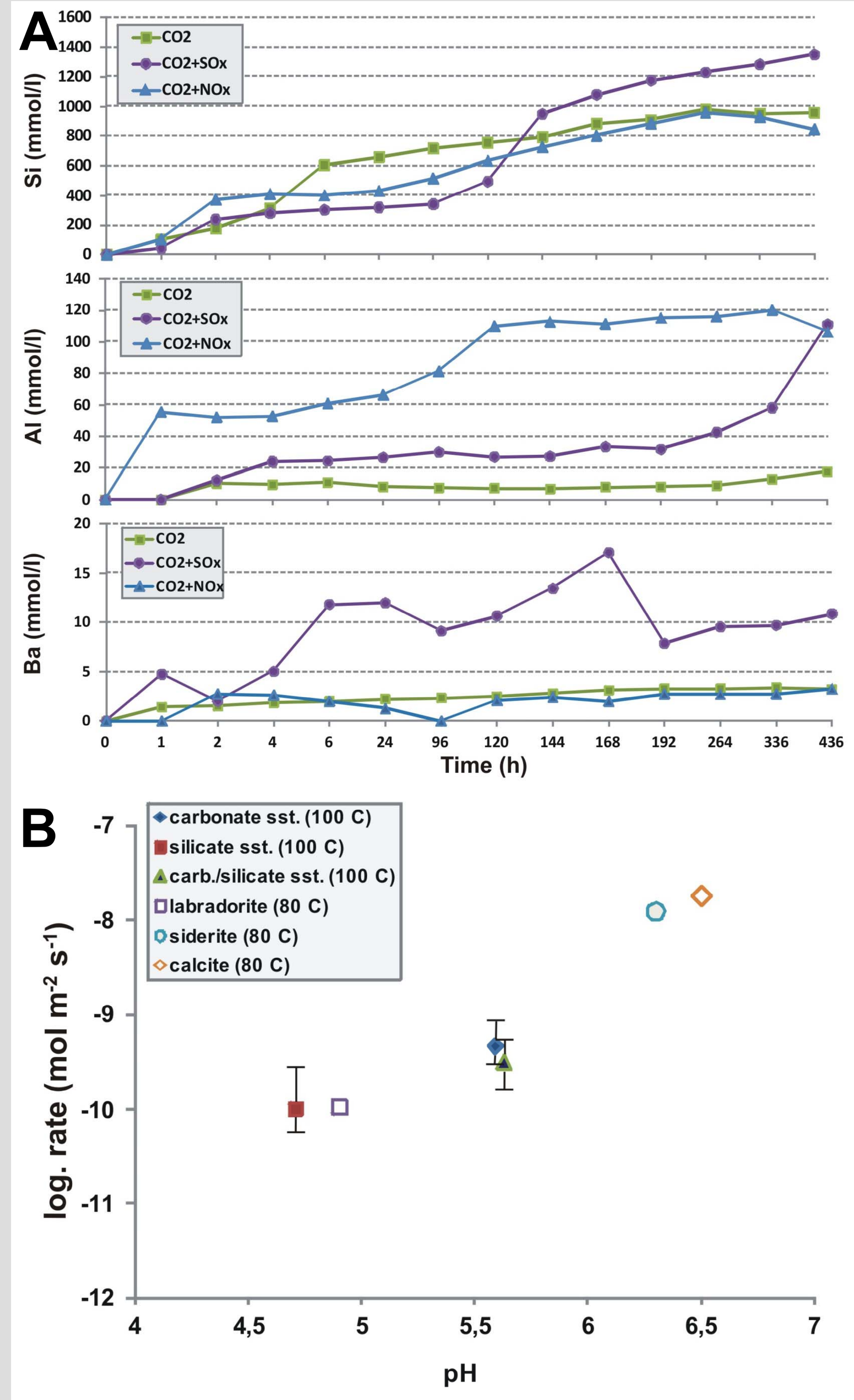

Fig. 5: Development of chemical fluid composition during alteration experiments on silicate sandstones (**A**); dissolution rates of bulk sandstone types and single minerals (**B**)

- **After exposure to brine and $scCO_2$ + SO_X or NO_X in the autoclave, samples show alterations i.e. dissolution effects of the carbonatic cements and of single minerals (Fig. 6 A, B) and also secondary mineral precipitations (C, D).**

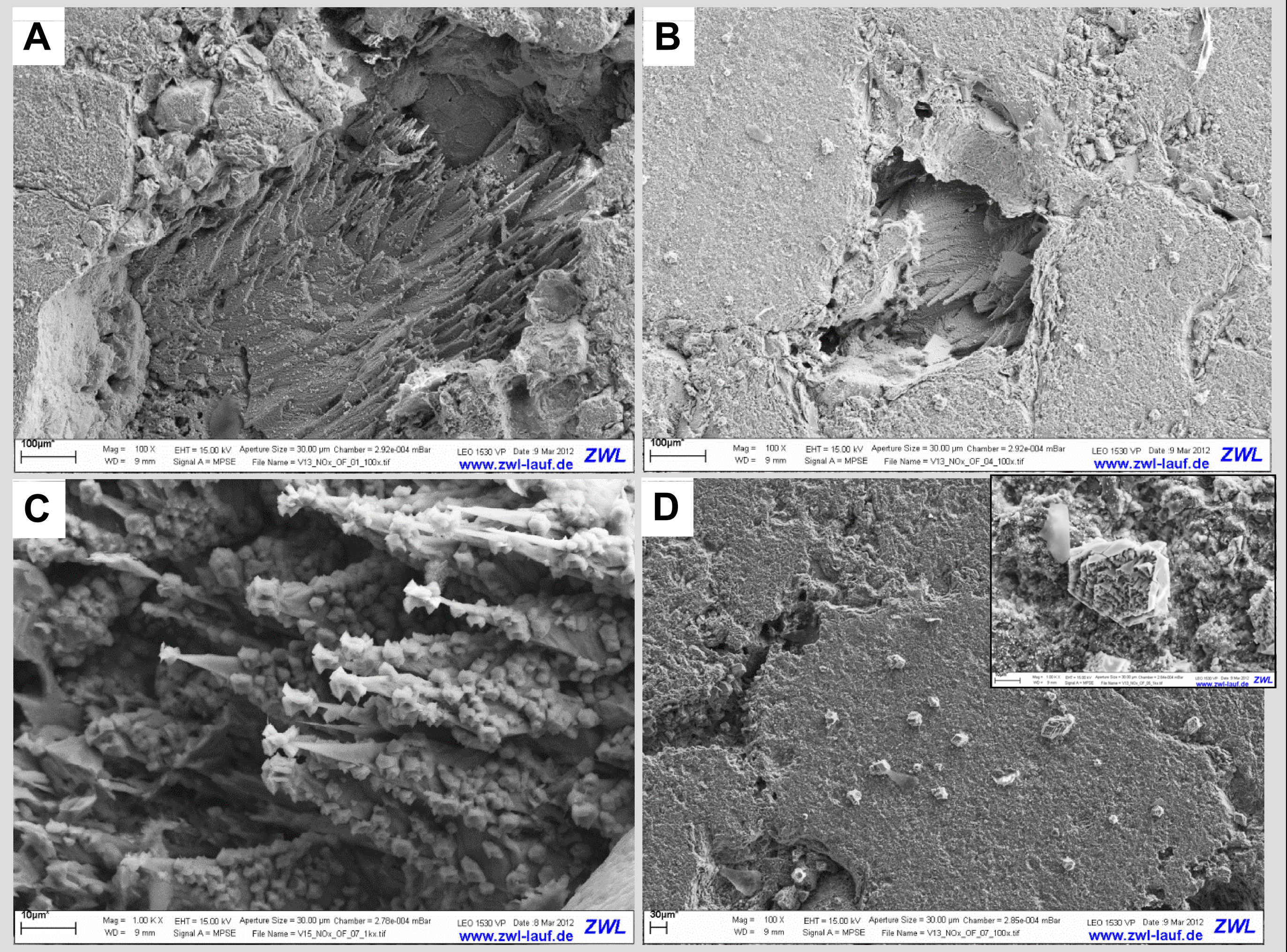

Fig. 6: SEM-images of silicate and carbonate bound Rotliegend sandstone samples after the treatment with brine and $scCO_2$ + 500 ppm NO_X in the autoclave. Images **A** and **B** shows dissolution effects on the carbonate matrix and **C** and **D** demonstrate secondary calcite precipitation axe-orientated on dissolved calcite tops (**C**) and on a carbonate surface (**D**).

- **Decrease of rock deformability (strain softening) due to the alteration with pure $scCO_2$ (Fig. 4).**
- **Increase of rock deformability (strain hardening) during the alteration under the influence of CO_2 + 1000 ppm SO_X (Fig. 4).**

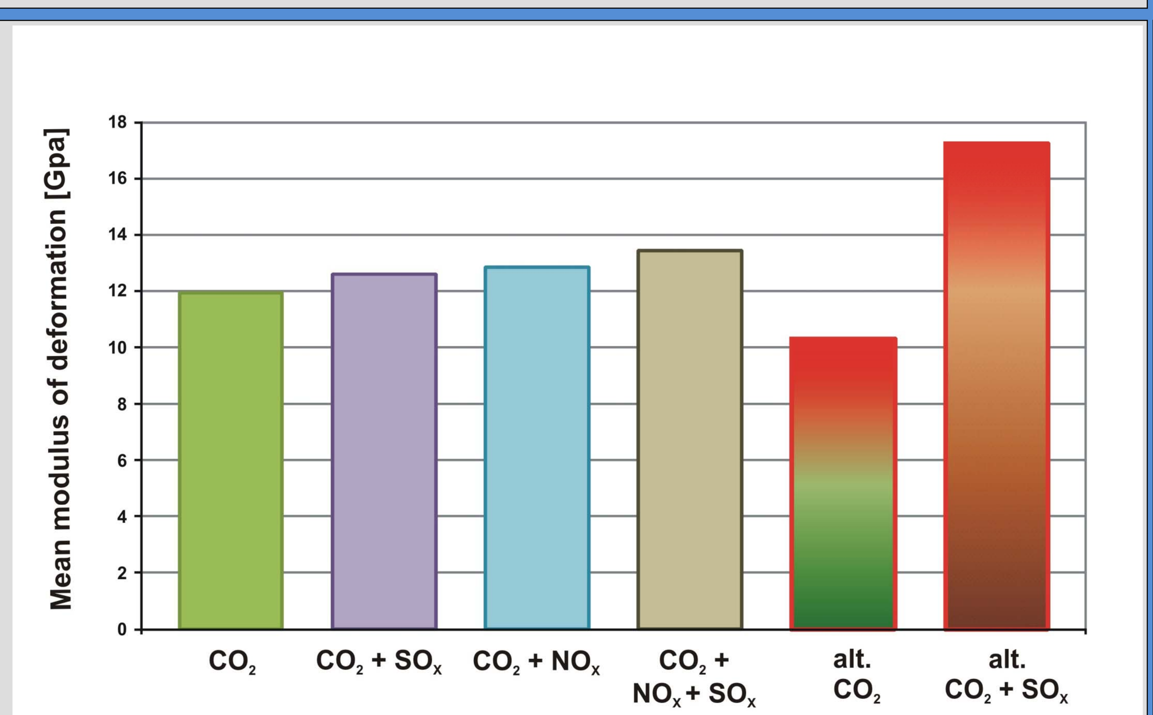

Fig. 4: Variation of elastic deformation properties (modulus of deformation) of silicate sandstone samples due to CO_2-alteration and the pore fluid chemical composition

Conclusions:

- **The strength behaviour of different types of sandstones varies with the degree of sample saturation, the pore fluid pressure, pore fluid chemistry and temperature.**
- **Various types of fluids cause different maximum differential stresses (effective stresses) at changing pressure conditions. This may be due to different pore space geometries and permeability.**
- **Different impurities in the reaction fluids in the autoclave (pure CO_2 + SO_X or NO_X) showing variable but generally increasing element dissolutions from the rocks (Ca, Si, Al, Ba) during the experimental course.**
- **The experimental determined differences in rock strength and elastic deformability of altered samples demonstrates clear trends of chemically induced mechanical weakening of the studied sandstones.**

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