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Development of porosity and elastic strain during burial of carbonate rocks

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Introduction

Chalks originate as pelagic or hemipelagic calcareous ooze of Cretaceous to Recent age, which via burial diagenesis can indurate to chalk and limestone. Because they accumulate in pelagic settings with high environmental continuity, chalks can be found as thick formations and even groups. For this reason they are ideal for the study of burial-related diagenetic processes and the consequent decrease in porosity. The depth related porosity reduction involves processes promoted by thermal energy and processes promoted by stress. Processes controlled by thermal energy include: 1) Recrystallization of calcite particles, leading to larger particles with smoother surface; 2) Transformation of clay minerals; which can involve dissolution of smectite and precipitation of localized illite, in this way forming stylolite precursors; and 3) transformation of opal to quartz. Porosity-reducing processes controlled by stress include: 4) Mechanical compaction of carbonate ooze and chalk; 5) Pressure dissolution at calcite-calcite contacts which causes transformation of ooze to chalk; and 6) pressure dissolution at stylolites. This is a source of calcium, which then diffuse to the location of porefilling cementation.

Based on information on depth, temperature and pore pressure and on core based porosity and P-wave velocity from Ocean Drilling Program and North Sea chalk fields, effective stress and elastic strain can be calculated, and the effect of stress related diagenetic processes on permeability and elastic strain can be demonstrated (Figure 1).

Results

The studied core data from calcareous ooze, chalk and limestone (indurated chalk) from three oceans and the North Sea basin, indicate that an elastic strain of 0.3% is critical for the onset of calcite-calcite pressure dissolution in ooze, and seems also to form a maximum for the elastic strain on chalk (Figure 1). During burial, elastic strain builds up in ooze until the critical 0.3% and then the contact cementation (caused by pressure dissolution) leads to stress release and the transition to chalk. In the chalk section elastic strain builds up again during burial before the abrupt transition to limestone. By contrast to the situation in soft sediments, burial and increasing pore filling cementation in the limestone leads to a decline in elastic strain with depth. North Sea hydrocarbon bearing chalk tend to have higher porosity than water zone chalk at a given effective stress, but at the same time are under higher elastic stain and for this reason under higher risk of pore collapse.

Conclusion

Stress-related diagenetic processes in chalk are found to be well illustrated in terms of elastic strain. The reason is that these diagenetic processes are controlled by the load on the grain contacts, so load should in principle be normalized to the contact area of these contacts rather the entire cross sectional area. In order to avoid ambiguity, resulting strain is a neutral choice.

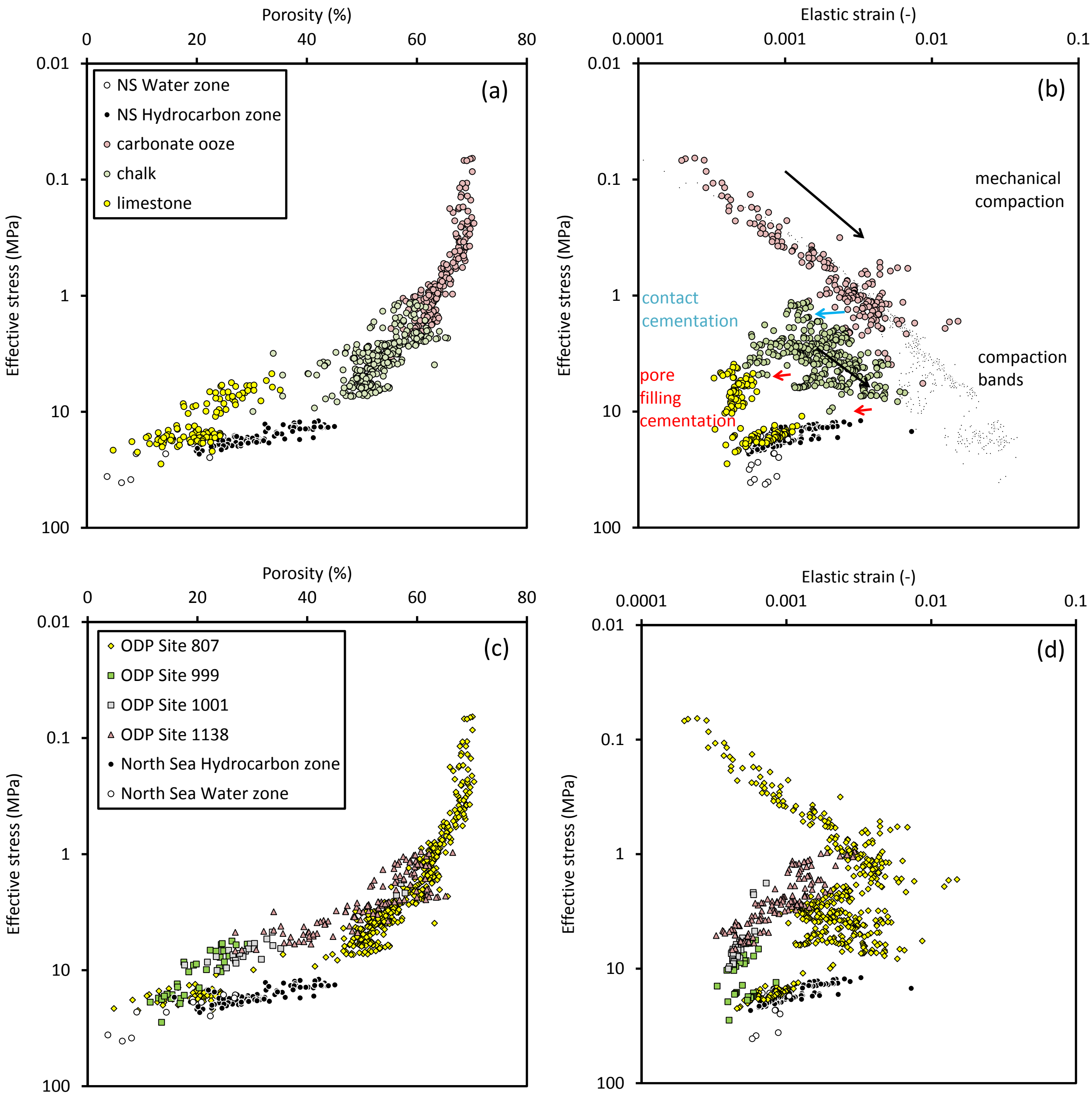

Figure 1: Porosity (a, c) and elastic strain (b, d) plotted versus in situ effective stress calculated by taking Biot's coefficient into account; effective stress can for these samples be seen as a normalized burial depth. The data points are coded according to lithology (a, b) or locality (c, d). The effect on elastic strain of diagenetic processes is annotated on (b): The large data points illustrate the elastic strain of intact samples, whereas the tiny data point illustrate the hypothetical elastic strain on the same samples following pore collapse. For carbonate ooze the difference is insignificant, whereas for chalk and limestone the difference in strain is substantial. Black arrows illustrate the effect of mechanical compaction, the blue arrow illustrate effect of contact cementation, whereas the red arrows illustrate the effect of pore filling cementation.

Acknowledgements

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