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Abstract

Influence of mechanical compaction and chemical diagenesis on the microfabric and fluid flow properties of Gulf of Mexico mudstones

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Abstract

We combine microstructural, mineralogical and pore network data to identify the key processes of compaction in a series of Gulf of Mexico mudstones buried to depths between 1.5 and 6 km. Mechanical compaction reduces mudstone porosities to 15% and permeabilities to 2–10 nD, without the development of a strongly aligned phyllosilicate fabric. The conversion of smectite to illite in the very hottest section has resulted in the development of a modestly aligned fabric, with an apparently related reduction in porosity and permeability. The results have implications both for the basic physical properties of mudstones (mechanical strength, seismic and permeability anisotropy) and for the way in which we model compaction and fluid flow in sedimentary basins.

Keywords: Mudstone; Compaction; Phyllosilicate fabric; Fluid flow

1. Introduction

The compaction of mudstones is a fundamental process in sedimentary basins, with important implications for fluid flow, the occurrence of overpressure and the entrapment of petroleum. For sandstones and carbonates, it is well established that compaction is driven by both mechanical and chemical processes. For mudstones, the impact of chemical processes on porosity-loss is less clear, despite the wealth of data describing the substantial mineralogical changes that characterise mudstone diagenesis. This study combines microstructural, mineralogical and pore network data on a series of mudstones from the Gulf of Mexico buried to depths between 1.5 and 6 km. At the very base of the section, the sequence passes through the smectite to illite transition, allowing us to investigate the effects of not only mechanical compaction but also mineralogical change on the fabric and the pore network of the mudstones.

2. Samples and methods

Samples of core and cuttings were taken from three wells in the deepwater Gulf of Mexico. The wells are

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sufficiently close together that they can be treated as a single, lithologically similar sample set. All samples are Miocene in age.

Grain size, clay mineralogy, porosity and pore size distributions were determined by well-established techniques. High-resolution X-ray texture goniometry (HRXTG; Van der Pluijm et al., 1994) was used to determine the average crystallographic orientation of individual phyllosilicate minerals over a sample area of 1 mm^2. The degree of particle alignment is expressed as maximum pole density in multiples of a random distribution [m.r.d.] where higher values reflect higher degrees of alignment. Previous studies (e.g. Ho et al., 1999) suggest that pole densities for mudstones range between 1.5 and 7 m.r.d., with values of 2–3 m.r.d. suggesting a weakly aligned fabric and values above 5 m.r.d. indicating a very strong fabric. Repeat measurements on the same sample indicate a reproducibility for the technique of around 0.2 m.r.d. For comparison, incipient metamorphism at temperatures above 180 °C can lead to cleavage development where maximum pole densities exceed 12–16 m.r.d. (Jacob et al., 2000).

3. Results and discussion

The key results are presented in Fig. 1. Clay fractions (particles with diameters less than 2 μm) are generally between 30% and 55%, and through most of the section, the proportion of illite in mixed-layer illite–smectite (I–S) is around 10%. It is only at the very base of the sequence, where temperatures exceed 120 °C, that the conversion of smectite to illite takes place. By 130 °C, the conversion is essentially complete. These temperatures are much higher than those typically observed for the smectite to illite transition, and presumably is a reflection of the reaction kinetics.

None of the samples show a strongly aligned phyllosilicate fabric. In these rapidly deposited, pro-delta mudstones, mechanical compaction has caused very little realignment of platy minerals normal to the maximum stress, despite burial depths of over 5 km, porosities of 15% and effective stresses over 20 MPa. These muds have not inherited a strongly oriented fabric at deposition and have not developed one during compaction that resulted in porosities of ~ 70% being

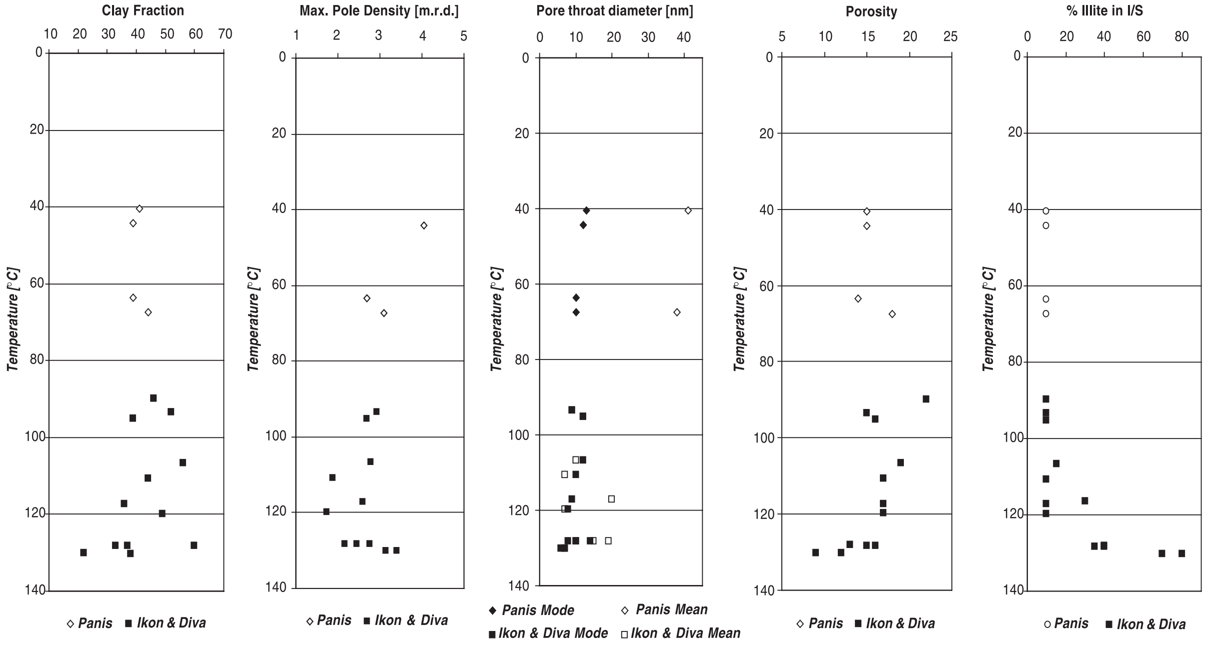

Fig. 1. Physical property data plotted as a function of temperature.

reduced to ∼ 15%. Purely mechanical compaction has thus led to mudstones with porosities of 15%, modal pore diameters of 10–15 nm and estimated permeabilities of 2–10 nD (see permeability model of Yang and Aplin, 1998).

The results of Ho et al. (1999) for mudstones from the shallow water Gulf of Mexico suggested that the recrystallisation of smectite to illite was associated with a major change in the alignment of phyllosilicates. Here, we see only minor evidence for realignment (Fig. 1). Nevertheless, the two most diagenetically mature samples do demonstrate a slightly enhanced fabric and show both the lowest porosities and the smallest modal pore sizes. There is therefore a hint in these sparse data that clay mineral recrystallisation in mudstones does lead to a more aligned microfabric, with the concomitant loss of porosity (from 15% to 8%) and permeability (estimated to be a reduction of 2–5). Despite the clear mineralogical changes, we speculate that these samples do not show a significant change in clay mineral alignment because they are in the earliest stages of a continuing recrystallisation process that would ultimately convert them into metapelites.

4. Conclusions

In these samples, mechanical compaction has reduced mudstone porosities to 15% and permeabilities to 2–10 nD, without the development of a strongly aligned phyllosilicate fabric. There are hints that the geologically recent conversion of smectite to illite has resulted in the development of a modestly aligned fabric, with a related reduction in porosity and permeability. The results have implications both for the basic physical properties of mudstones (mechanical strength, seismic and permeability anisotropy) and for the way in which we model compaction and fluid flow in sedimentary basins.

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