

SILICA DIAGENESIS AND POROSITY PRESERVATION IN DEVONIAN RESERVOIRS FROM THE SOLIMÕES BASIN, NORTHERN BRAZIL

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Resumo – Arenitos devonianos marinhos rasos da Formação Uerê são importantes prospectos de óleo na Bacia do Solimões, Amazônia ocidental. Os reservatórios são arenitos progradacionais com contatos basais abruptos, depositados em um complexo de plataforma dominado por tempestades, e recobertos por folhelhos pretos de Frasniano-Fameniano que são as rochas geradoras de petróleo da bacia. Concentrações de espículas de esponjas ocorrem intercaladas com os arenitos, como restos de esponjas individuais ou coloniais, recristalizadas a nódulos, lentes e camadas de chert. Apesar de sua grande extensão lateral, a exploração desses arenitos é dificultada pelos intensos e heterogêneos processos diagenéticos que fortemente afetaram a qualidade dos reservatórios. A porosidade dos arenitos varia de extremamente fechada (menos de 5 %), a valores anormalmente altos (até 28 %), considerando-se a longa e complexa história de soterramento dos reservatórios. Os principais processos de redução da porosidade são a compactação mecânica e química e a cimentação por crescimentos secundários de quartzo, por carbonatos (siderita e dolomita) e por illita fibrosa. A porosidade primária dos reservatórios porosos foi preservada pela inibição dos crescimentos de quartzo e da dissolução por pressão por franjas eodiagenéticas de quartzo microcristalino ou calcêdônia, localmente associadas a cutículas de argilominerais esmectíticos. Tal precipitação diagenética precoce de sílica está relacionada à dissolução de espículas de esponjas silicosas. A transformação da fase de alta entropia (opala amorfa) na fase de baixa entropia (quartzo) ocorreu segundo um percurso de dissolução-reprecipitação controlado termodinamicamente e cineticamente. Cutículas de argilas esmectíticas podem ter acelerado a transformação opala-quartzo competitivamente adsorvendo sílica. A cimentação mesogenética por crescimentos de quartzo é heterogênea da escala de lâmina delgada à de camada. Isto é atribuído à inibição dos crescimentos pela presença das franjas de quartzo microcristalino, e à convecção de fluidos quentes promovida pelo magmatismo triássico. Os reservatórios porosos eram originalmente arenias híbridas ricas em espículas de esponjas silicosas, depositadas por tempestades.

Palavras-Chave: diagênese de arenitos; franjas de sílica; preservação de porosidade; qualidade de reservatórios

Abstract – Shallow marine Devonian sandstones of the Uerê Formation are important oil prospects in the Solimões Basin, western Brazilian Amazon Region. The reservoirs are sharp-based, progradational sandstones, deposited in a storm-dominated shelf complex, and overlain by Frasnian-Famennian black shales, which are the basin oil source rocks. Concentrations of sponge spicules occur interbedded with the sandstones, as remnants of isolated and colonial sponges, recrystallized to chert nodules, lenses and layers. In spite of their large lateral extent, the exploration of these sandstones is complicated by intense and heterogeneous diagenetic processes, which strongly affected reservoir quality. The porosity of the sandstones range from extremely tight (less than 5 %) to abnormally high values (up to 28 %), considering the long and complex burial history of the reservoirs. The main processes of porosity reduction are mechanical and chemical compaction and cementation by quartz overgrowths, carbonates (siderite and dolomite) and fibrous illite. The primary porosity of porous reservoirs was preserved by the inhibition of quartz overgrowth cementation and pressure dissolution by grain-rimming, eogenetic, microcrystalline quartz or chalcedony, in places associated to smectitic clay coatings. Such early diagenetic silica precipitation is related to the dissolution of siliceous sponge spicules. The transformation from the phase of highest entropy (amorphous opal) to the phase of lowest entropy (quartz) occurred in a dissolution-reprecipitation pathway thermodynamic- and kinetically controlled. Smectitic clay coatings, may have accelerated the opal-quartz transformation by competitively adsorbing silica. Mesogenetic quartz overgrowth cementation is heterogeneous from thin section to layer scale. This is attributed to inhibition of overgrowth by the presence of eogenetic microcrystalline quartz rims, and to the convection of hot fluids promoted by Triassic magmatism. The porous reservoirs were originally storm-reworked, hybrid sands rich in siliceous sponge spicules.

Keywords: sandstone diagenesis; silica rims; porosity preservation; reservoir quality

1. Introduction and Setting

The Solimões Basin is a large cratonic sag that covers around 600,000 km² of northwestern of Brazil, filled by up to 4.5 km of marine to continental Palaeozoic deposits, and Cretaceous to Tertiary continental sediments, and Late Triassic to Early Jurassic diabase sills and dykes (Eiras et al., 1994). Large reverse faults and asymmetrical folds constitute the main hydrocarbon traps. Although the basin has been explored throughout the past three decades, little is known about the controls of the reservoir quality from the Devonian Uerê Formation sandstones. Most of the exploration efforts were concentrated in the sandstones of the Carboniferous Juruá Formation, which contain the largest gas accumulations of Brazil (close to 200.10⁹ m³ of gas *in place*, and 11.10⁶ m³ of associated oil *in place*). The remote geographic location of the Solimões Basin, and the extremely high costs of gas production and transportation have increased the interest in the exploration for the Devonian sandstones. This is because they contain mainly oil, occur throughout most of the basin, and are closely associated to the main source rocks of the basin, the Jandiatuba shales (Mello et al., 1994). The studied Upper Devonian sandstones are interbedded with shales and cherts, and unconformably cover Middle Devonian deposits and Precambrian metasediments and granitoids. Their base is a regional erosional surface, and top is a maximum flooding surface, covered by the Jandiatuba shales. The stratigraphy and facies associations suggest deposition within an overall progradational regime, followed by a major transgression. The storm reworking of nearshore siliceous sponge biostromes allowed the deposition of spiculites and spicule-rich (hybrid) arenites bellow the fair-weather wave base depths. Exploration of the Uerê sandstones is complicated by the heterogeneous quality of the reservoirs, which range from highly porous (up to 28 %) to extremely tight. The objective of this study is to unravel the depositional and petrologic controls on the quality of the Uerê reservoirs.

2. Results

The main diagenetic processes affecting the Uerê sandstones are the authigenesis of various forms of silica, particularly microquartz rim cements, which occur in originally spicule-rich, hybrid arenites, and mechanical and chemical compaction.

Three reservoir petrofacies were defined, based on the porosity, intergranular volume, and types and amount of silica cementation (Fig. 1): Petrofacies A: porous sandstones (>15 %) with microquartz rims (Fig. 2A); Petrofacies B: tight (<10 % porosity), strongly compacted, moderately quartz-cemented (< 6 %) sandstones (Fig. 2B); Petrofacies C: moderately porous (10-15 %), conspicuously quartz-cemented (> 6 %) sandstones (Fig. 2C).

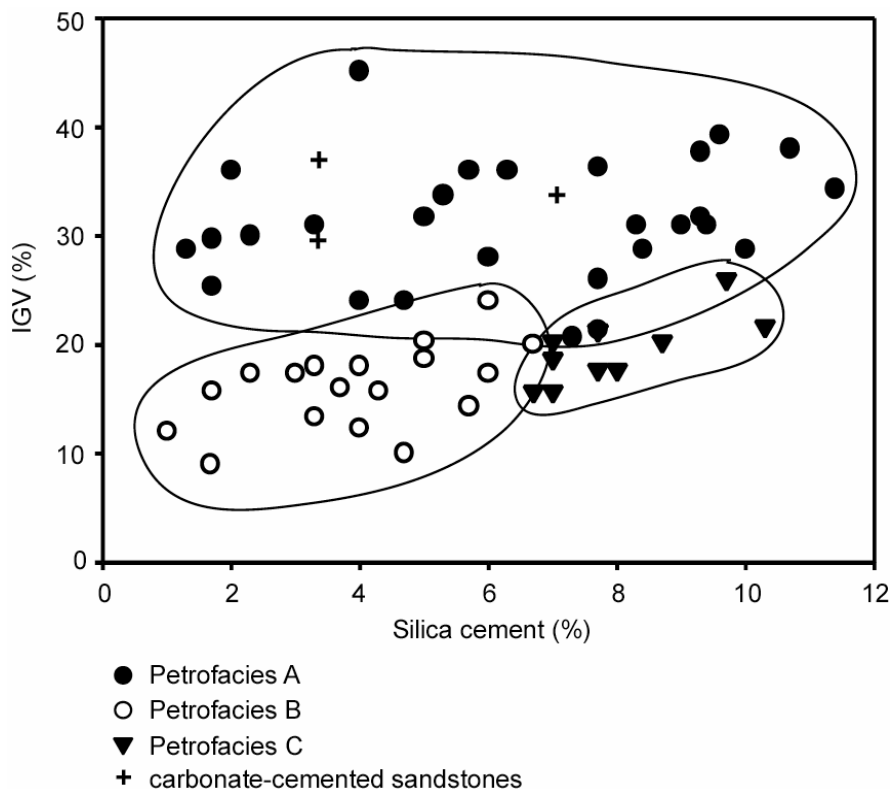


Figure 1: Plot of the of silica cement volume (chalcedony, microcrystalline and macrocrystalline quartz) versus intergranular volume, showing a clearly distinction between the three reservoir petrofacies.

Four major diagenetic evolution stages were recognised (Fig. 3): (1) marine eodiagenesis, dominated by the dissolution of sponge spicules and precipitation of silica (restricted to petrofacies A), and siderite/dolomite; (2) meteoric eodiagenesis, responsible for heterogeneous feldspar dissolution and kaolinite precipitation; (3) shallow mesodiagenesis (< 2600 m depth), marked by heterogeneous chemical compaction and quartz overgrowth cementation; and (4) deep mesodiagenesis (> 2600 m depth), marked by illite authigenesis and further quartz precipitation, probably connected to the convection of hot fluids related with Triassic magmatism. Thermal maturation of Devonian shales and hydrocarbon emplacement in reservoirs took place at this time.

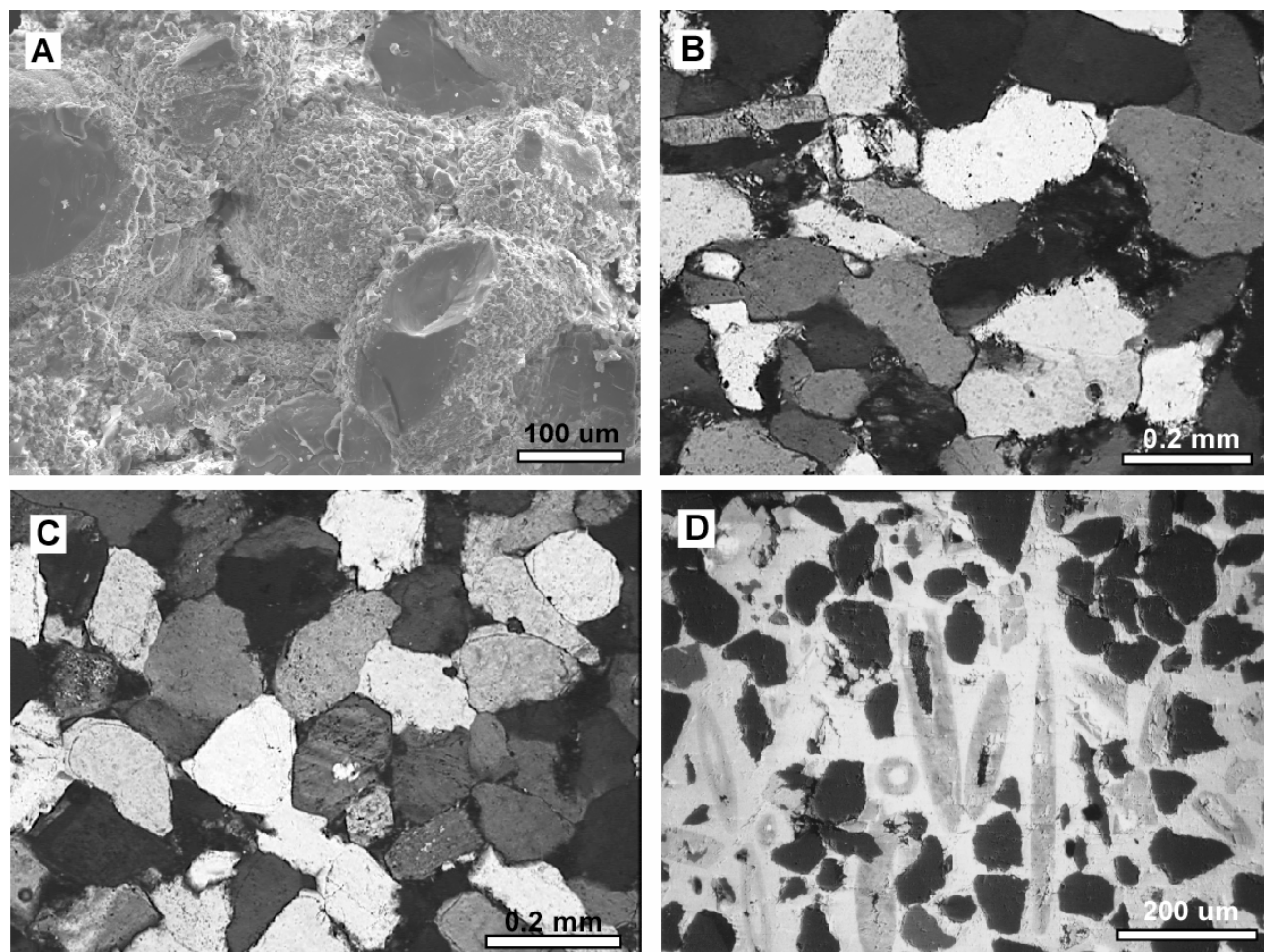


Figure 2: (A) Secondary scanning electrons microscopy image of a porous petrofacies A sandstone cemented by microcrystalline quartz rims. (B) Optical photomicrograph of a strongly pressure-dissolved petrofacies B sandstone with thin illite coatings. (C) Optical photomicrograph of a petrofacies C sandstone massively cemented by quartz overgrowths. (D) Backscattered electrons microscopy image of a petrofacies A sandstone cemented by Fe-dolomite with “ghosts” of replaced sponge spicules.

Mouldic pores after spicules, widespread within petrofacies A sandstones, as well as ghosts of spicules within early carbonate cement (Fig. 2D), indicate a major redistribution of silica from biogenic sources to the eogenetic cements. A thermodynamic-kinetic model explains the progressive diagenetic silica transformation from the phase of highest entropy (amorphous opal) to the phase of lowest entropy (quartz) in a dissolution-reprecipitation pathway. The scarcity of opal-CT remnants is probably related to the occurrence of eogenetic smectitic clay coatings, which accelerated the opal-CT/quartz transformation and/or competitively adsorbed silica, thus inhibiting opal-CT nucleation.

Mesogenetic quartz overgrowth cementation is heterogeneous from thin section to layer scale. This is attributed to inhibition of overgrowth by the presence of eogenetic microcrystalline quartz rims, and to the convection of hot fluids promoted by Triassic magmatism.

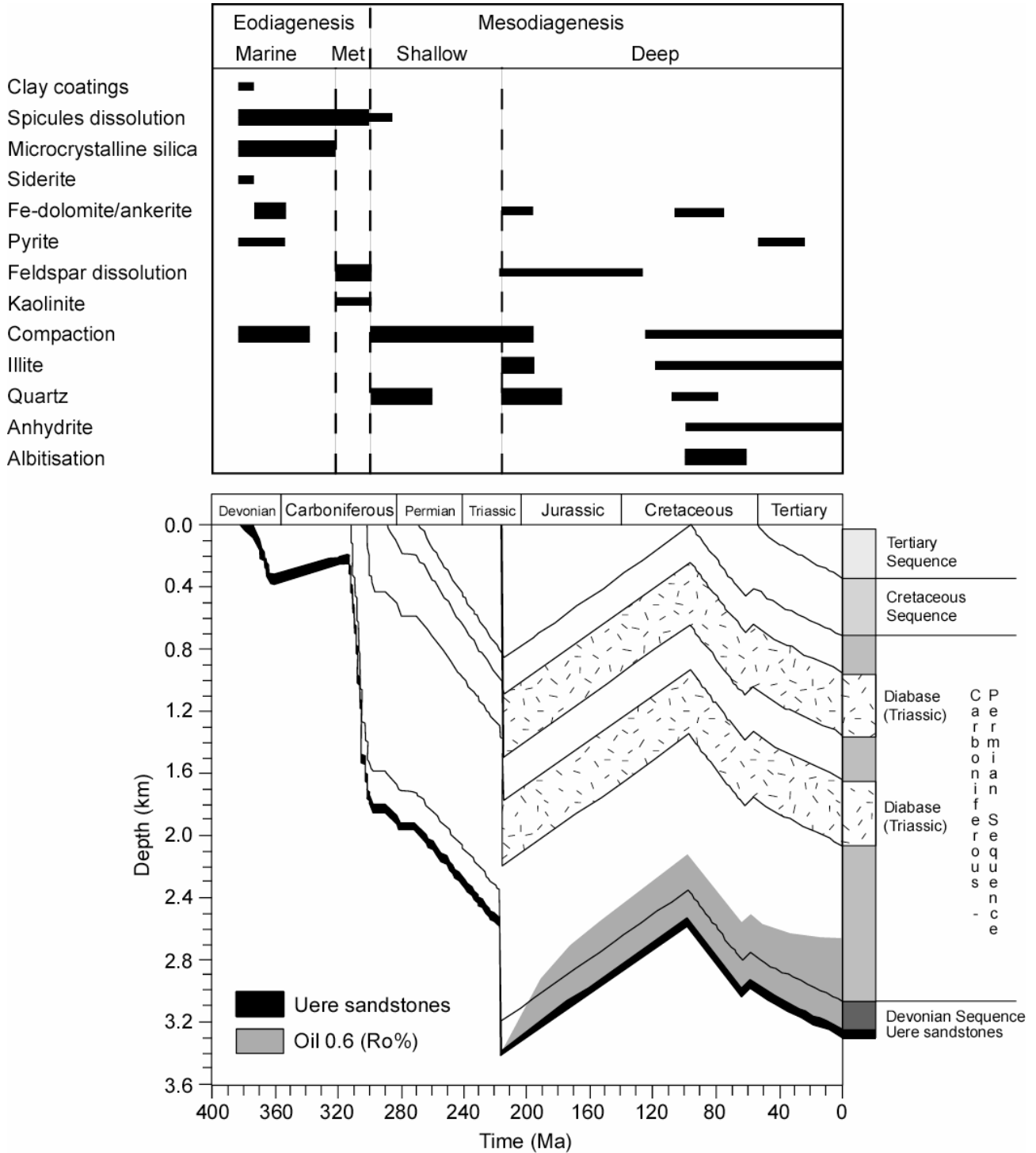


Figure 3: Diagram of the paragenetic sequence and burial history of the Uerê sandstones in the São Mateus oil field.

The major mechanism of porosity preservation is the inhibition of quartz overgrowth cementation and pressure dissolution by eogenetic microquartz rims (Fig. 4), as observed in some other marine reservoirs (Hendry and Trewin, 1995; Aase et al., 1996; Ramm et al. 1997; Osborne and Swarbrick, 1999; Bloch et al., 2002). The distribution of the eogenetic silica cements (grain-rimming and pore-filling microquartz, chalcedony) and associated clay coatings is directly related to storm layers rich in sponge spicules.

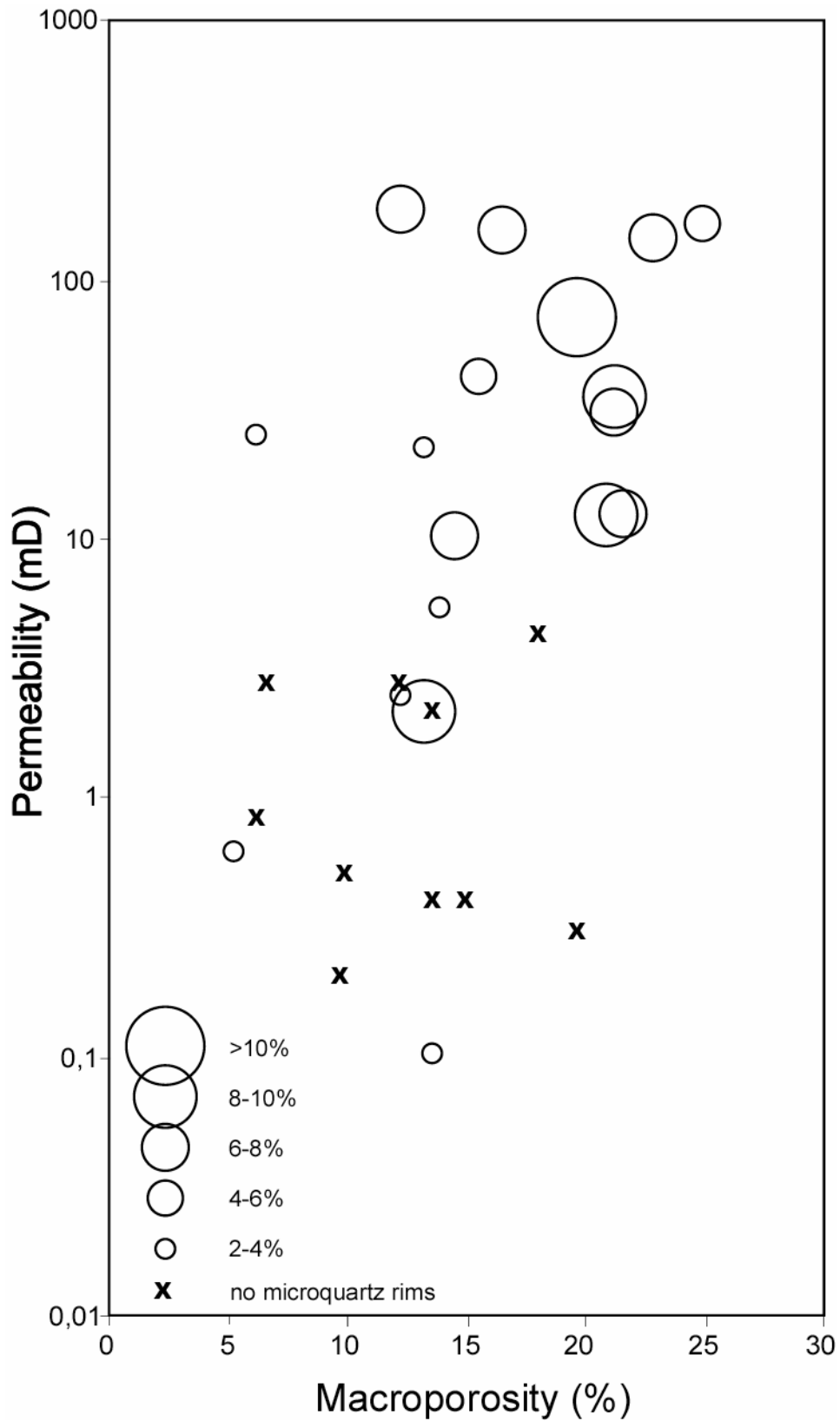


Figure 4: Plot of thin section macroporosity versus horizontal air permeability, with symbols representing the amounts of microcrystalline silica rims in sandstones from petrofacies A. Some samples devoid of microquartz present relatively high macroporosity values due to the presence of clay coatings which preserved porosity from quartz overgrowths, however decreasing permeability.

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