# DIAGENESIS OF THE SANDSTONES OF A TIGHT-GAS RESERVOIR: THE LAJAS FORMATION IN THE HUINCUL HIGH, NEUQUÉN BASIN

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The sandstones of the Lajas Formation represent the main tight-gas reservoir of the Neuquén Basin. Diagenesis plays a fundamental role in this type of reservoir because diagenetic minerals have a high impact on porosity and permeability. This study presents the diagenetic characterization of the Lajas sandstones located in the productive area of Sierra Barrosa, central part of the Huincul High in the Neuquén Basin. The objective is to evaluate diagenetic processes and their impact on reservoir quality.

The facies analyzed belong to deltaic and fluvial depositional systems with a variety of sub-settings including delta front (proximal and distal mouth bar), prodelta, delta plain (distributary channels and interdistributary bays), fluvial channel infill and fluvial plain deposits. The analyzed samples consist of very coarse-grained to fine-grained, medium- to poorly-sorted and texturally immature feldspathic litharenites and lithic feldarenites (*sensu* Folk *et al*. 1970) along with siltstones and subordinate fine-grained clast- and matrix-supported polimictic conglomerates. Detrital minerals include lithic fragments, mono- and polycrystalline quartz, and feldspar with K-feldspar>plagioclase. Lithic fragments are volcanic and volcanoclastic detritus and subordinate plutonic, sedimentary and metamorphic grains. The amount of cement varies considerably and includes pyrite, clays, quartz, feldspar, carbonates, barite and subordinated Zn-Pb sulfides. Porosity depends on facies and their amount of cements.

The analyses indicate that, during early diagenesis, framboidal pyrite (Py1) precipitated as a result of bacterial sulfate reduction of aqueous sulfate. Framboidal pyrite occurs in fine-grained sandstones and siltstones in bioturbation traces and in phytoclasts, as well as disseminated in coarse-grained sandstones. Cubic pyrite crystals are commonly associated with framboidal pyrite suggesting recrystallization of earlier framboids. Kaolinite and berthierine were formed during eodiagenesis. Crystal size, blocky habit and composition of kaolinite close to ideal stoichiometry (Si2Al2O5 (OH4)) support a diagenetic origin. It is inferred that, with increasing burial, berthierine was progressively converted to Fe-rich chlorite (according to the intensity of d001 << d002 in XRD), as it is the most plausible mechanism for Fe-chlorite crystallization in clastic sedimentary formations (Beaufort *et al*. 2015). Quartz cement with different texture varieties (i.e., overgrowths, outgrowths, pore-filling and microcrystals (Qz1)) precipitated mostly in coarse-grained sandstones with low clay content, occluding the intergranular pore spaces. In sandstones with predominance of chlorite rims, quartz precipitation was inhibited, hence porosity was preserved. Fine-grained overgrowths of albite (~20 µm) show bitumen impregnations; these overgrowths are very common but due to their small size, their effect on porosity reduction is negligible.

Hydrocarbons upflow promoted grains dissolution and carbonate precipitation as evidenced by floating texture and primary hydrocarbon-bearing fluid inclusions with yellow and blue fluorescence under ultraviolet light; similar hydrocarbon-bearing fluid inclusions occur as secondary trends in detrital grains. Carbonates fill primary and secondary intergranular porosity and replace detrital grains. Microchemical and X-ray diffraction analyses indicate the presence of Fe-rich carbonates such as ferroan dolomite, ankerite, and siderite. Zoned crystals vary from ferroan dolomite to ankerite. In other cases, parallel bands of ferroan dolomite alternate with ankerite, typical of oscillatory zoning; ankerite also fills micropores and cleavage planes in ferroan dolomite. The complex textural relationships observed argue for a progressive Fe-enrichment of the diagenetic solutions with time. Pressure-solution features and microstylolitization surfaces in carbonate crystal contacts indicate strong compaction after carbonate precipitation.

After the peak of compaction, basinal brines enriched in Zn and Pb entered in the sandstone reservoir and reacted with hydrocarbons, generating organic acids which partially dissolved previous cements and detrital grains, hence creating secondary porosity. Aqueous sulfate reduction induced the precipitation of sphalerite, galena and pyrite (Py2), minerals that lack signs of compaction. Impregnations of bitumen in the sphalerite crystals highlight the role of hydrocarbons as a reducing agent for the sulfides precipitation.

The X-ray diffraction analysis indicate a self-similar clay mineralogy in all samples analyzed, consisting of a mixture of illite/smectite mixed layers very rich in illite (I/S) and Fe-rich chlorite. Illitization of detrital clays (smectite), diagenetic clays (kaolinite) and K-feldspar provided silica and barium to the solutions, favoring the precipitation of secondary quartz (Qz2) and barite in the enhanced porosity, which do not show compaction features pointing to late precipitation.

Mesoporosity measured with an optical microscope records the highest values in coarse-grained sandstones and the lowest in cemented conglomerates and fine-grained sandstones with high clay content. Porosity measured in the petrophysical laboratory is considerably higher than mesoporosity recorded in thin section analyses (*e.g.* 8.3% versus 1%, respectively), however permeability is always very low (<0.1mD).

The results of this study emphasize the strong compaction and cementation that the Lajas reservoirs underwent through their burial history. However, porosity was enhanced at different stages by dissolution, in turn caused by the upflow of hydrocarbons and basinal brines. The coarse-grained sandstones present better reservoir characteristics than the conglomerates, commonly pervasively cemented, and better characteristics than the fine-grained sandstones and siltstones, commonly recording high clay content. Mesopores are better preserved in Fe-rich chlorite cemented sandstones because chlorite coatings inhibit quartz cementation, hence coarse-grained sandstones cemented with Fe-rich chlorite represent the best reservoir facies. Differences in the measured porosity imply the presence of abundant microporosity associated to clay cementation, as documented in the deeply buried sandstones of the Athabasca Basin where illite aggregates cementing the intergranular volume may reach 70% of microporosity (Sardini *et al.* 2009).

Beaufort, D., Rigault, C., Billon, S., Billault, V., Inoue, A., Inoue, S. and Patrier, P. 2015. Chlorite and chloritization processes through mixed-layer mineral series in low temperature geological systems - a review. Clay Minerals 50: 497-523.

Folk, R.L., Andrews, P.B., and Lewis, D.W. 1970. Detrital sedimentary rock classification and nomenclature for use in New Zealand. New Zealand Journal of Geology and Geophysics 13: 937-968.

Sardini, P., Abderrazak El, A., Pret, D., Gaboreau, S., Siitari-Kauppi, M. and Beaufort, D. 2009. Mapping and quantifying the clay aggregate microporosity in medium- to coarse-grained sandstones using the 14C-PMMA method. Journal of Sedimentary Research 79: 584-592.