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Linking Diagenetic Styles to Reservoir Quality: the Eolian Nugget Sandstone (Jurassic), SW Wyoming

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Petrographic study of 36 core samples of the Nugget Sandstone from two wells at Anschutz Ranch East Field (12,000 to 13,800 ft) in the Utah-Wyoming thrust belt revealed that textural and packing heterogeneities resulting from different depositional mechanisms in the eolian environment was a primary control on its diagenetic evolution (Lindquist, 1988). The aim of this work is to describe the different diagenetic patterns that have been observed in these eolianites in order to evaluate the relative impact they exerted on the hydrocarbon reservoir quality properties.

Studied samples are clean, well to very well sorted, very fine to medium-grained subarkoses (average $F_{74}M_2C_{22}P_2$:$Q_{82}F_{13}R_5$). Framework grain fraction is clearly dominated by abundant monocrystalline quartz and subordinated K-feldspar grains (the absence of plagioclase is noticeable). Minor components are polycrystalline quartz, felsitic volcanic rock fragments, chert, quartz-rich schistose rock fragments, and some granitic rock fragments. Partially dissolved K-feldspar grains and chert are common, as well as chloritized and/or illitized rock fragments. Less frequently, some feldspar grains have been replaced by calcite, dolomite, or kaolinite. Matrix is very scarce (always less than 10% and generally less than 1-2%); it appears as irregular, tangential illitic (?) clay rims that suggest an infiltrated origin (Matlack et al., 1989), or as dispersed pore-filling material. Total porosity has quite variable abundance; air porosity ranges from 18 to 1%, and optical porosity ranges from 11 to 0% (the difference among them reveals significant amounts of microporosity). Primary (intergranular) porosity has been reduced by both compaction and cementation. Evidences of compaction include: a) present values of intergranular pore spaces that are significantly lower than depositional porosities in eolian subenvironments (Schenk, 1983; Atkins and McBride, 1992), b) common fracturing of quartz, and sometimes of K-feldspar grains, and c) ductile deformation of clay-rich rock fragments and argillitized (feldspar?) grains. Most abundant cements include silica as quartz overgrowths (exceptionally as outgrowths); chlorite as thick pore linings and bridges among grains; and calcite/dolomite as a massive phase, irregular patches or isolated, millimeter-sized nodules. Hematite as grain coats and irregular patches can be locally abundant, being responsible for the reddish coloration. Other cements include K-feldspar overgrowths (sometimes detached from the seed grain by further compaction) and minor pore-filling kaolinite. Bitumen fills larger pores in some of the samples. Some minor secondary porosity (mainly microporosity) has been generated by partial dissolution of some feldspar, chert and rock fragment grains.

Based on the main types of eolian stratification described by Schenk (1983), four main lithofacies were recognized in the studied samples: avalanche (A), grainfall (G), ripple (R) and deformed (D) strata. These lithofacies are frequently combined in a centimeter-or millimeter-scale interlamination. Thus, the main elements for sample classification were the textural and fabric features of the sandstones, such as grain size, sorting, packing, and presence of microstructures (massive vs. laminated, graded, etc.). Each of these lithofacies is characterized by a particular diagenetic pattern that would ultimately control the reservoir quality characteristics of the rock, as shown by the decreasing trend in the values of air porosity (18 to 1%) and permeability (70 to 0.03 md) from avalanche, grainfall, and ripple up to deformed strata (Figure 1).

Avalanche strata (A) exhibit the best reservoir quality characteristics (air porosity 18-6%; optical porosity 11-0%; permeability > 0.2md). They are made up of clean, medium- to fine-grained sandstones exhibiting an open packing. The relatively coarse grain size, good sorting and lack of matrix determined the presence of abundant intergranular porosity in large pores. It is worth noticing that primary porosity has been preserved as a result of well developed chlorite coats that significantly inhibited quartz overgrowth development (cf. Pittman et al., 1992). Isolated nodules of calcite and dolomite that give the rock a "mottled" appearance are also frequently present.

Grainfall strata (G) are massive, fine to very fine-grained sandstones showing intermediate reservoir quality characteristics (air porosity 16-2%; optical porosity 8-0%; permeability 20-0.03md). Intergranular porosity decreased, and a smaller mean grain size with respect to the avalanche strata also determined smaller and more tortuous pores. Chlorite coats are less abundant, making quartz overgrowths the main cementing phase, together with scarce calcite/ dolomite patches, and minor hematite. Some secondary porosity by grain dissolution is noticeable, although it does not significantly improve reservoir quality because of its poor connection and small pore size characteristics.

Ripple strata (R) have poor reservoir quality characteristics (air porosity 8-2%; optical porosity 1-0%; permeability < 0.2md). The microlaminated and inversely graded fabric (from coarse silt to medium-grained sand) exerts a clear control on the porosity and permeability distribution. Primary porosity, if not occluded by carbonate cementation, is always restricted to lamina tops. Chemical compaction, on the other hand, is evident at lamina bases, where stylolites, quartz overgrowths, and hematite coats and patches are common. Matrix is particularly abundant in this lithofacies, mostly as tangentially-oriented illitic (?) clay coats. The close association among stylolites, quartz overgrowths and matrix suggest that the "clay-induced dissolution" mechanism (Bjørkum, 1996) may have locally favored quartz dissolution and concomitant overgrowth development, also preserving hematite-rich coats from later bleaching.

Deformed strata (D) exhibit the poorest characteristics from the reservoir quality point of view (air porosity < 2%; optical porosity 0%; permeability < 0.02md) and can be considered as "flow barriers". They include wavy and/or bioturbated massive or rippled very fine sandstones with minor matrix and abundant hematite. The unusually open packing and presence of "exploded grains" are evidences of an early and displacive carbonate (calcite/dolomite) cementation at shallow depths.

Finally, tectonic overprint originated deformation bands and calcite-cemented veins that generally have a negative impact on the reservoir quality characteristics at a very small scale in any of the above described lithofacies (cf. Fisher and Knipe, 1998).

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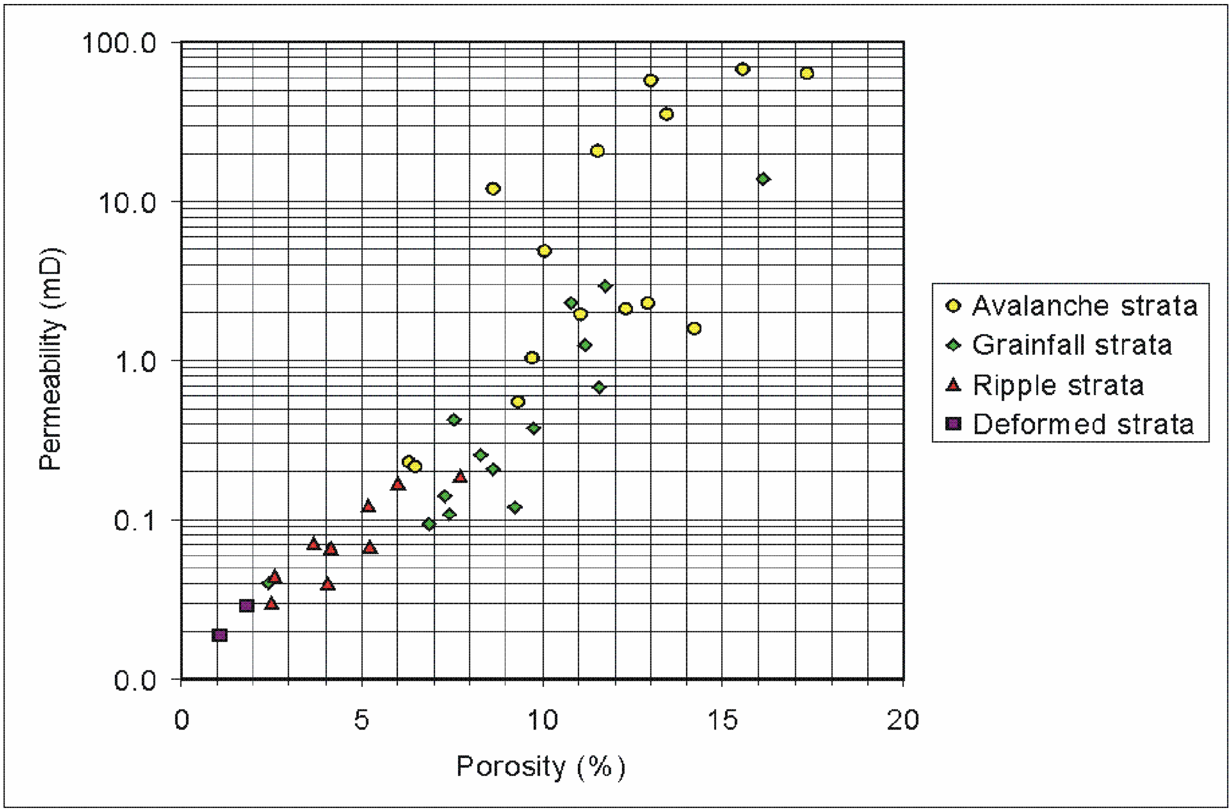

Figure 1 - Porosity and permeability data from Nugget Sandstone samples at Anschutz Ranch Field East. See text for lithofacies code explanation.