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Diagenesis of Ordovician Sandstones from the Ahnet Basin, Algeria

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Summary

The Ahnet Basin lies on the site of the former Pan-African (750-550Ma) trans-Saharan orogenic belt. It is known to have undergone special evolution marked by a high heat flow (Takherist & Lesquer, 1989) that resulted in very advanced evolution of organic matter and poor primary reservoir quality.

This presentation reports on the diagenetic changes that Ordovician sandstones have undergone through time to find out the factors that controlled reservoir properties.

The Ordovician formations consist of fine sediments that have been deposited in various sub-environments of a shallow marine clastic shelf with glacial influence towards the end of deposition. The reservoir facies consist of fine-grained sandstone having low primary porosity and permeability (less than 10% and 0.01mD, respectively) but which are often fractured. Textural evidence shows that severe compaction, cementation by quartz overgrowths, and growth of filamentous illite have reduced significantly reservoir quality. Point counts of thin sections show that porosity loss due to compaction ranges from 60 to 90%. Fluid-inclusion data suggest two main episodes of quartz cementation: (1) From 130 to 175^{0}C interpreted as a Pre-Hercynian burial and compaction phase; (2) from 175 to 230^{0}C (possibly as high as 256^{0}C) interpreted as a Post-Hercynian major thermal event. Illite crystallinity (by Weaver index) shows variation with lithology; nevertheless, it corroborates fluid inclusion data and suggests that sediments have undergone incipient to weak metamorphism.

Introduction

The Ahnet Basin is located in the south central part of the Algerian Sahara desert. It is adjacent to the northern margin of the Hoggar shield to whom its structural evolution is closely related. It shows passive margin subsidence with thermotectonic (hot-spot) overprinting (Sahagian, 1993). Its Palaeozoic sedimentary cover is mainly clastic.

The Ahnet Basin was the site of the first hydrocarbon (gas) discovery in the Sahara in the early 1954. The Ordovician and lower Devonian sandstones have yielded notable quantities of dry gas during testing. This study is part of larger integrated analysis of both depositional and diagenetic fabrics of Ordovician and Devonian sandstones. Its purpose is to determine the factors that controlled reservoir characteristics (porosity - permeability). The present study examines the diagenetic analyses, fluid-inclusions microthermometry, scanning electron microscope investigations, and petrographical study of thin sections that were carried out on samples from the cores. The results of these analyses give a good insight into the burial conditions (i.e. temperature, subsidence history and fluid chemistry) under which diagenesis processes have destroyed reservoir quality.

Methods and objectives

Fifty-seven samples were collected from approximately 600 m of cores from three boreholes (BH-301, MKRS-1 and DT-1), they represent all the variation in depositional and diagenetic fabrics displayed by Ordovician formations (core depths range from 402 to 2920 m). Selected sandstone samples were impregnated with blue-dyed epoxy-resin to highlight porosity in thin sections. Point counts of thin sections were used to quantify the detrital framework grains, intergranular volume and cement in order to evaluate the relative effect of compaction and cementation on sandstone porosity (e.g. Ehrenberg, 1995). Selected samples also were examined under the scanning electron microscope (SEM) fitted with energy-dispersive X-ray microanalysis (EDX) to identify clay morphology and trace element chemistry and, to determine the three-dimensional relationships of cement-porosity. Poroperm data from eight boreholes relate to textural relationships. X-ray diffraction (XRD) analyses were undertaken on all the collected samples to further identify and quantify bulk mineralogy. Analyses of clay fraction (<2μm) were used to determine the illite crystallinity (sharpness ratio). Following petrographical studies, those samples displaying fluid inclusions within quartz overgrowths and within quartz veins were chosen for fluid-inclusion studies to determine temperature of quartz cementation and composition of pore fluids that existed in the sandstone at the time of cementation. The timing of quartz cementation is documented by combining fluid-inclusion data with previous thermal and burial histories reconstructed from apatite fission track analysis (AFTA), zircon fission track analysis (ZFTA), etc.

Results

The average framework grain composition of thirty-two sandstone samples from the studied wells is 97% quartz, 3% feldspar (dominantly K-feldspar) and 0% unstable lithic fragments. All the samples are classified as quartzose sand from continental block provenance with sources on stable craton. Authigenic mineralogy consists of quartz overgrowth cement, filamentous illite, patchy carbonate cement (calcite, siderite, ankerite), pyrite and albite. The analysis of sixty-two feldspar grains using energy dispersive analyser (EDX) shows hat albite is pure with little chemical variations of Na2O. Illite shows high degree of crystallinity and its variation was in part controlled by sediment lithology.

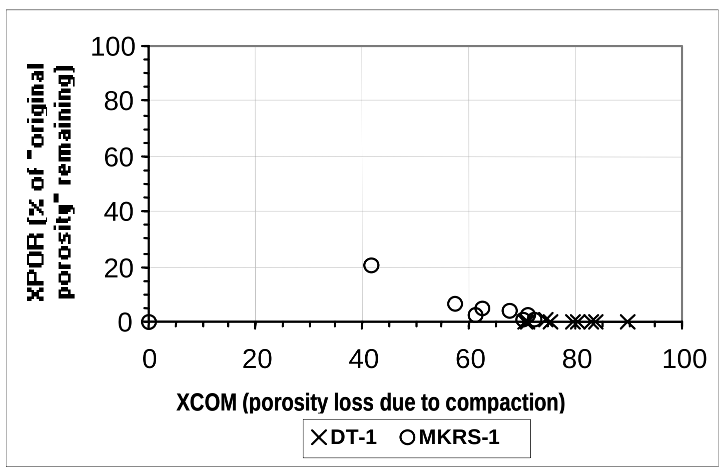

Figure 1. Variation of XPOR vs XCOM shows that the remaining "original porosity" is less than 10% and 60 to 90% of porosity loss is due to compaction

Thin section porosity ranges from 0 to 8%, the samples from shallower depths (in a range of 400 to 500m depth in MKRS-1) show relatively high porosity. As shown in Figure1, 60 to 90% of porosity loss is due to compaction and in all samples the remaining "original porosity" is <10%. Similarly core porosity from eight boreholes is less than 10% with permeability of 0.1 and 0.01 md. Cementation of quartz overgrowths averages 8% of the total rock volume.

The results of Th and Tm ice measurements (Fig.2) indicate that precipitation of quartz overgrowths has taken place at temperatures within the range of 135 to 175^0 C from variable salinity brines with depth (1.23 to 4.18 wt% NaCl). The fluid inclusions trapped within quartz fracture-filling cement suggest that quartz cementation formed progressively at elevated temperatures in the range of 175 to 230^0 C from moderate salinity brines decreasing from 5.56 to 3.87 wt% NaCl.

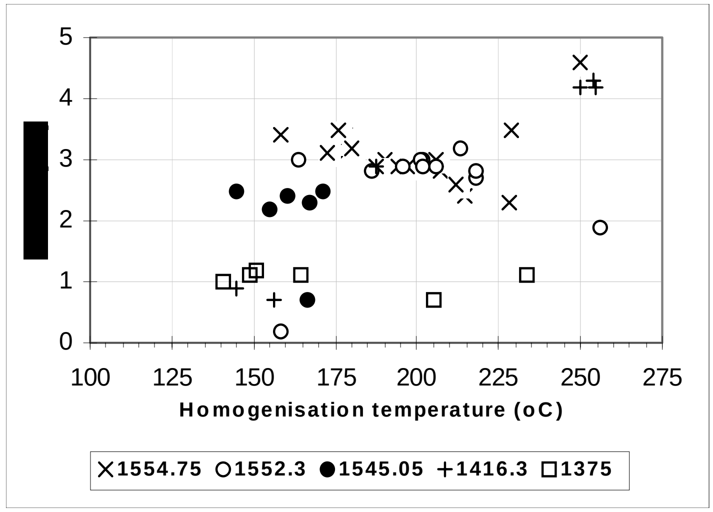

Figure 2. Distribution of Th and Tm ice from fluid inclusions trapped within quartz overgrowths (B8 and B25) and within quartz fracture-filling cement (B27 and B28). Note variation of Tm ice with depth in the former assemblage with Th in range of 135 to 175^0 C.

Conclusions

1. The Ordovician sandstones from the Ahnet Basin represent highly mature detritus. They consist of a quartzose sand with a typical continental block provenance. Quartz is, by far the most abundant detrital mineral, averaging more than 97% of the framework composition and is mainly monocrystalline. Feldspar constitutes less than 3% and unstable lithic fragments are generally absent.

2. The main diagenetic events that modified the sandstone primary textures and mineralogy, in approximate time sequence, are: (1) early non-ferroan calcite cement, (2) precipitation of quartz cement, (3) albitization, (4) illite cement, (5) continued quartz-pressure solution, (6) precipitation of chlorite, and (7) formation of late Fe-calcite, siderite and ankerite. Mechanical compaction affected the sediments throughout burial.

3. Textural evidence shows that compaction is the dominant process of porosity reduction during burial in relation to cementation of quartz overgrowths. Precipitation of scattered pore-filling and pore-lining filamentous illite has strongly contributed to permeability destruction. The secondary porosity, formed by feldspar dissolution, is quantitatively insignificant.

4. In all samples the remaining “original porosity” (XPOR) is in the range of 0 to 10%, with an average value of 3% in thin sections. For such quartz-rich sands, reduction of porosity from an initial value of 35 to 40% to a final value of 10 to 15% could be expected at depths of burial of about 6 to 7 km or more (Dickinson & Suczek, 1979).

5. The initial porosity appears to be retained in the sandstones as a direct function of grain size. A similar trend is observed with the amount of quartz cement (it increases with increasing grain size). However, the severity of quartz cementation and compaction processes is related to the amount of intergranular pressure solution which is not only due to simple burial, it is rather activated by very high temperatures (high thermal gradient), which prevailed after structural deformation.

6. Fluid-inclusions data suggest two main episodes of quartz cementation:
   - From 130 to 175^{0}C, it is interpreted as Pre-Hercynian burial and compaction phase, during which increased burial to approximately 4700 m led to the first generation of hydrocarbon (i.e. essentially oil) from Ordovician, Silurian and Devonian source rocks.
   - From 175 to 230^{0}C (possibly as high as 260^{0}C) it is interpreted as Post-Hercynian major thermal event marked by dolerite intrusions dated by K-Ar analysis at 200 Ma (early Jurassic) in the Reggane Basin. This thermal event has consequently engendered thermal cracking of existing liquid hydrocarbons to dry gas, and activated destruction of reservoir properties.
7. Melting ice temperature (Tm ice) show variation with depth indicating that pore waters were not well mixed. This suggests that there is no large scale convection and the silica was produced close to sites of quartz precipitation from dissolution of quartz at stylolites and grain contacts.
8. Finally, although reservoir qualities are very poor in relation to the extent of the thermal episode, the Ordovician sandstones (typically the “Hamra quartzites”) are known to have yielded notable quantities of dry gas (during well testing) related to an important fracturing. The quite good correlation between grain size and diagenetic events (compaction, quartz cementation and illitization) can provide a basis of forward modelling for prediction of better matrix porosity which will enhance fracture production. This means that the understanding of facies distribution would help to define better play.