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The Importance of Diagenetic Processes in Sandstones Facies of the Hamakoussou Sedimentary Basin in North Cameroon: Influence on Reservoir Quality.

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Abstract

Published studies in the Hamakoussou reservoir sandstones are very few and the characterization of the reservoir quality including diagenesis is unknown. In this paper, after lithological reports, classical petrographic techniques have been used to study the diagenesis and reservoir quality of the Hamakoussou sandstones: Diagenetic processes within and around detrital grains show that early cementation by calcite come from volcanic veins and late cementation originating from silicification. Diagenetic phenomena (early cementation, compaction, fracturation and late cementation) show that these sandstones have a low porosity due to the blockage of intergranular pore spaces by cement. Intense volcanic activity associated with the circulation of fluids (silica and calcite) as well as the dissolution along the contacts of quartz grains are the principal sources of early and late cements which are responsible for the decrease in porosity observed in these sandstones. The immediate consequence is the sudden drying up of boreholes drilled for water supply.

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***Keywords*:** Diagenesis; Porosity; Reservoir; Cementation; Dissolution/Precipitation; Hamakoussou Sandstone.

1. Introduction

The aim of this study is to describe the processes of the creation and destruction of porosity and their impact on water yield during diagenesis in the Hamakoussou sandstone sedimentary basin (Fig 1b) situated between latitudes 9°30’ to 9°40’ and longitudes 13°30’ to 13°40’. This Lower Cretaceous basin, which stretches close to 20 km E-W and N-S width of maximum 5 km [1], has a surface area of approximately 65 km^2 and altitudes that ranges between 350 m and 420 m. The Garoua sandstone [2] is an extension of the Benue trough into Cameroon (Fig 1a) and constitutes a huge reservoir from which water is drawn to supply the entire city of Garoua. According to Cameroon Center for Hydrological Research, the Garoua sandstone is one of the largest water reservoirs in Cameroon with estimated 27 billions of cubic meters of groundwater. Contrary to the Garoua region, well and boreholes within Hamakoussou experienced a sudden dry-up thereby making water a progressively rare commodity in this locality. The study of diagenetic phenomina of the Hamakoussou sandstone reservoir enables us to describe porosity creation and destruction.

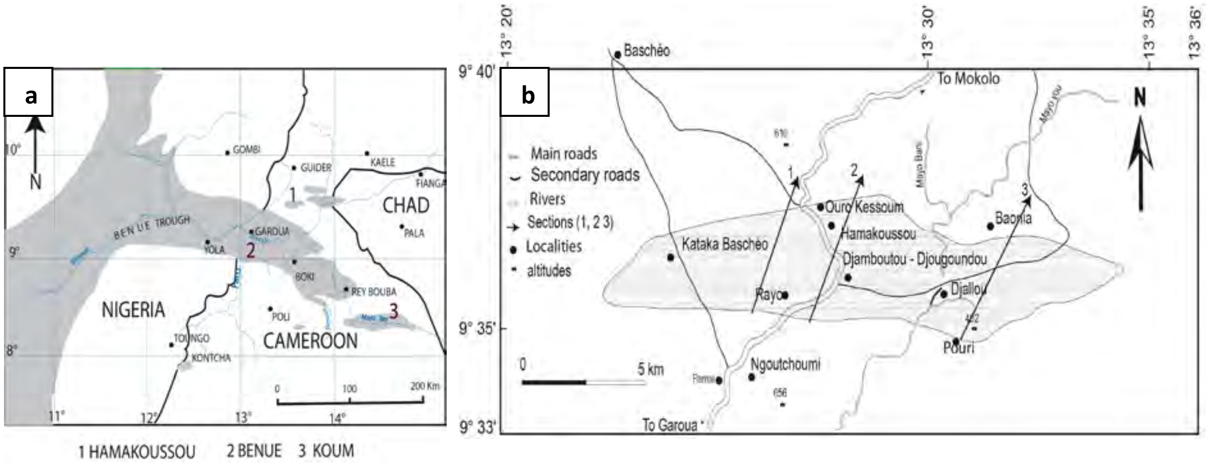

Figure 1: Location of the Hamakoussou Basin

2. Samples and Methodology

This study is based on a total of 30 samples representing different types of sandstone in three profiles (Fig. 1b) from the Hamakoussou sedimentary basin. The first section (1) is located in the Pamsi locality situated in the western corner; the section (2) in Ourokessoum located at the centre and the third section (3) in Djallou in the East. Each of these profiles runs from the South to the North, and also enabled the assessment of the different facies types. After a complete facies study of the basin, the sandstone facies was selected because of the nature of the grain size of the elements depicted and the ease of performing petrographic observations in order to better understand the phenomena of cementation, compaction, dissolution and recrystallization. The chemical or physical reduction of the porosity of the sediments was observed based on the distribution of diagenetic cement (calcite and silica), and the contacts between the detrital grains (quartz, feldspars, micas and heavy minerals) by the rearrangement of the grains and the dissolution processes. The contact interfaces between the quartz grains as well as quartz overgrowths were analyzed in order to control their influence on the primary porosity of the sandstones. Thirty samples were selected for this work from which, thin sections were prepared at the University of Montpellier thin section laboratory in France. Petrographic analysis was done at IPHEP laboratory in Poitiers (Nikon ECLIPSE E600 POL microscope), and at the Ore processing Laboratory (LTM) in the Institute for geological and Mining research (IRGM), Cameroon (Novex XP-201 microscope). The observations were done under polarized light and non-polarized light petrographic microscope.

3. Geological setting

The Benue trough (Fig. 1a) which was established as a result of the opening of the Atlantic is an intra-plate tectonic structure extending NE-SW. This trough covers a distance of ≈1000 km long stretching from the Niger Delta to Lake Chad and 50 to 150 km wide, filled with marine and continental sedimentary rocks (thickness > 6 500 m) and dates from Lower Cretaceous to Quaternary [3]. The Benue trough is divided into two branches: the Gongola branch with an N-S direction which extends into the Niger, and the Yola-Garoua branch trending E-W which elongates into Cameroonian territory. The Hamakoussou Basin (Fig. 1b) is one of the sedimentary basins associated with the Yola-Garoua branch, thus the half graben structure was formed during sedimentation [4]. The Hamakoussou Basin reveal a lacustrine depositional environment formed on a Precambrian basement which comprises essentially quartzites, migmatites; and the granitic intrusions, form part of the Eburnean or Archean materials while the other part is made up of materials of the Panafrican age ([5, 6, 7, 8, 9, 10, 11]). This sedimentary series is bounded in the South by an E-W fault on a pink micro-granite.

4. Results

4.1 Lithology

Hamakoussou Basin is composed dominantly of sandstone with interbedded Shale (Sh); Marlstones (Ms), and volcanoes (Fig. 3). This sandstone is made of fine, medium, coarse and very coarse pebbly sandstone. Bed thickness of sandstones varies between 15 cm and 2.50 m. The orientation of beds ranges from N05°, N15°, N135°, N65°, N90°, N110° and N75°. The abundance Sandstones of approximately 60% are constituted by: Micro conglomeratic sandstones (Ssg); massive coarse sandstones (Ssm), oblique and cross fine to coarse stratified sandstone (Sst); horizontal laminated fine-grained sandstone (Ssh), (Fig. 2 B), and siltstones (Sss). Some of these facies reacted positively to 10% HCl. Massive conglomerate facies (Gsm) are also common and these conglomerates consist essentially of quartz pebbles and bedrock fragments (granite) with centimetric to decametric dimensions (Fig. 2A). Furthermore, intermediary facies were identified showing a gradual transition from the fine sandstones to siltstones (Fig. 2 C). The shales (Sh*)* population between 10-20 % (Fig. 2 C) is well distributed throughout the vertical profile of the formation and is divided into three sub facies: Calcified shales, indurated shales with carbonated mud (septaria) and laminated shales. Attempts to recover plant remain (silicified tree trunks) conchonstracans, micro flora, fish scales and bivalves. The calcified shales are found near volcanic input due to their proximity with magma (Fig. 2 D).

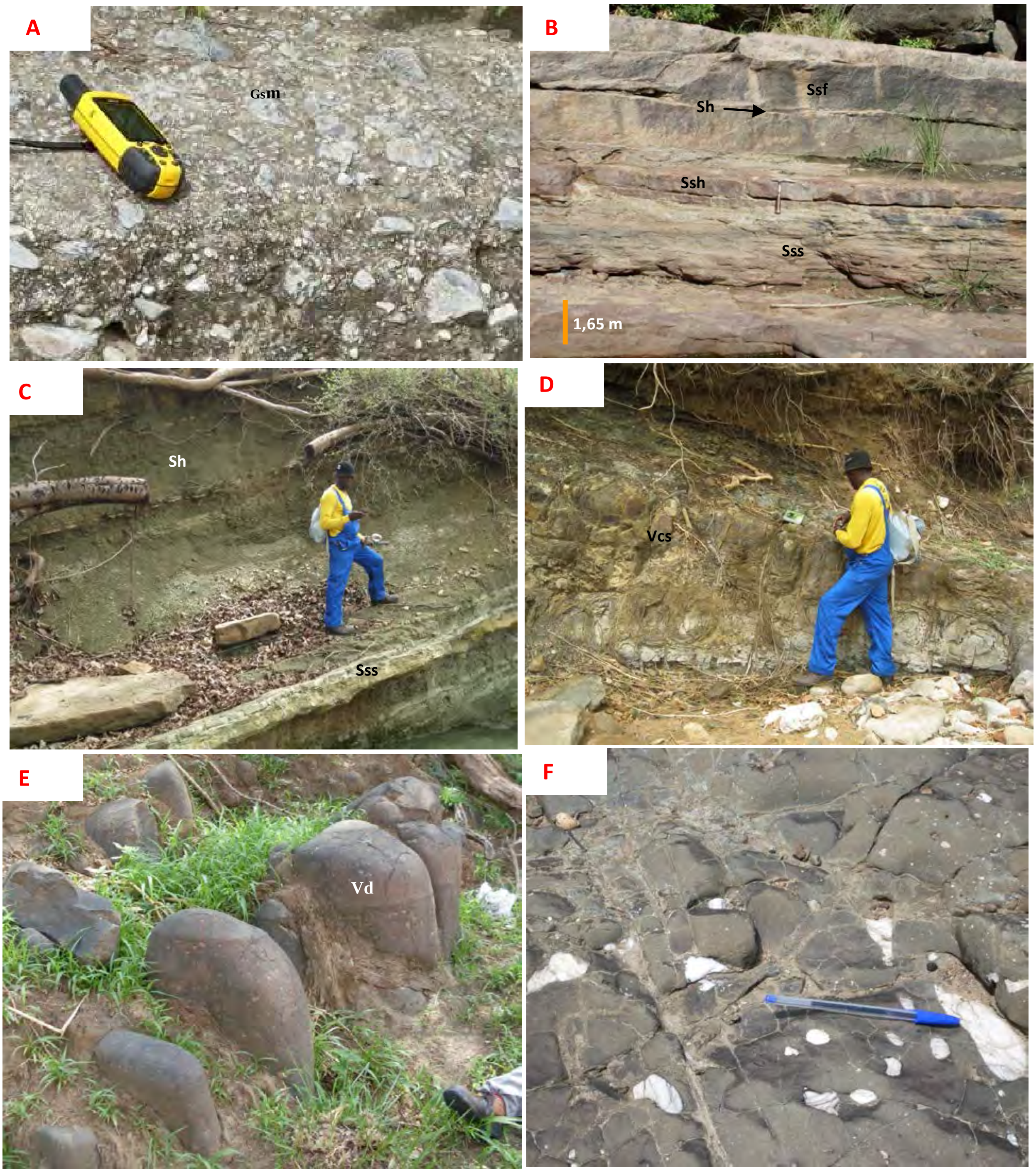

Figure 2: A selection of facies of the Hamakoussou sedimentary Basin. A- Polygenic conglomerates consisting of quartz and granite clasts in sandstone cement. B- Layers of shales (Sh), (1-2 cm) interacted in a succession of metric thickness of fine sandstone (Ssf) and siltstone (Sss) which are also cemented by calcite. This type of succession possibly reflects poor source rock potential in term of reservoir. C- Shale with intercalation of sandstone carbonated bed. D- Volcano clastic sill (Vcs) with exfoliation surfaces intercalated in shale. E- Volcanic dyke (Vd). F- Lineation of eye-shaped calcite mineral in volcanic sill.

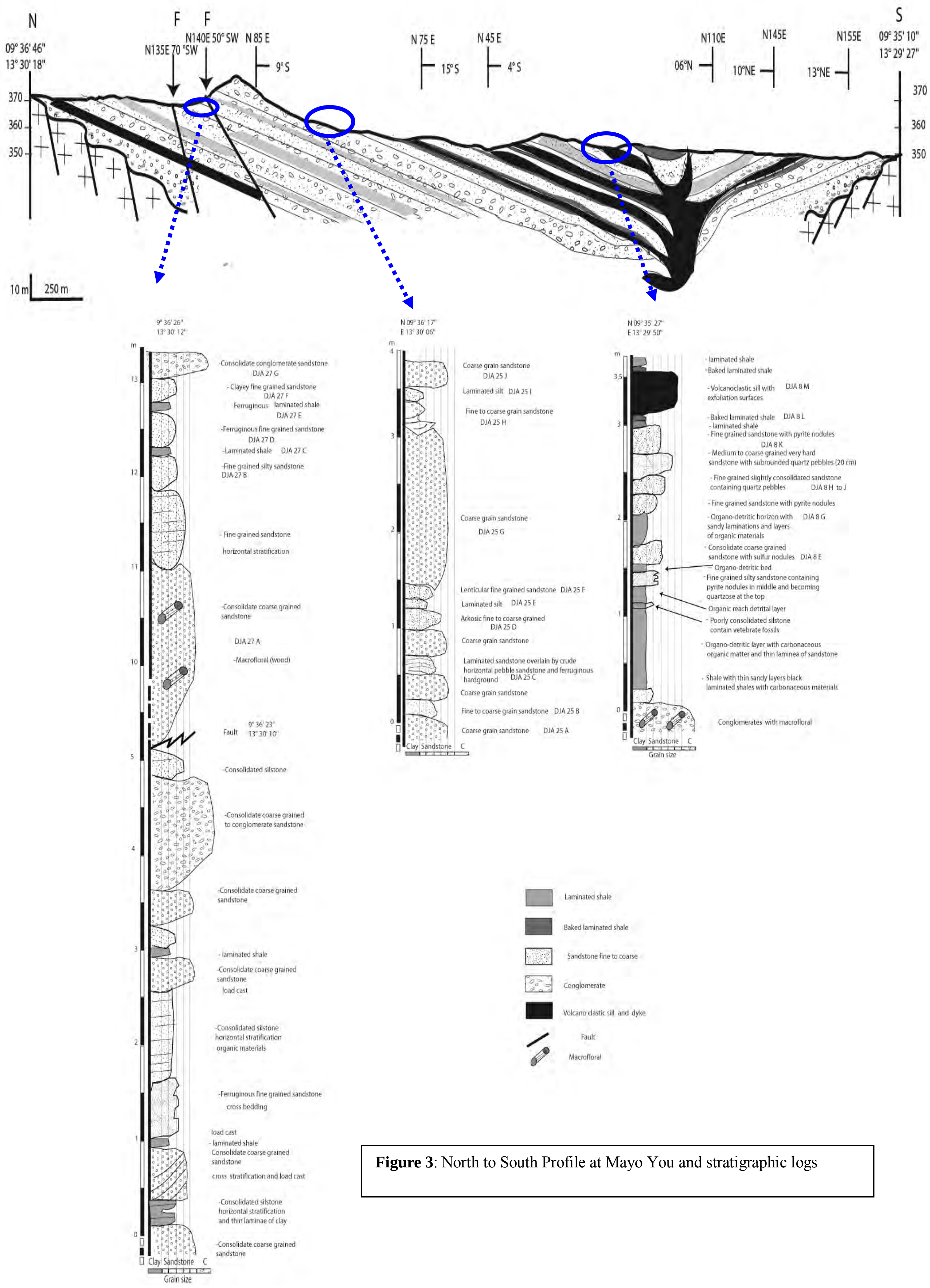

Figure 3: North to South Profile at Mayo You and stratigraphic logs

Bed thickness varies between a millimeters to a maximum of 7 m. Some marlstones (Ms*)* occur as fine intercalations in the shales with a thickness less than 10 cm. The volcanics facies (V*)* 10% sometimes rich in calcite lenses (Fig. 2 F) mostly represented here by dykes (Vd*)*, (Fig. 2 E) or by simply veins as pillow lavas which are 1 to 3 meters thick (Vcs*)*, (Fig. 2 D).

4.2 Cement and diagenesis

The sandstones of Hamakoussou are made up of quartz and feldspars grains cemented to a greater or lesser extent by silica which crystallized around the grains in the form of: continuous crystalline quartz with these quartz (Fig. 4G, 4H), by calcite and iron oxides (Fig. 4D) or simply by a clayey sandstone matrix around the detrital grains. Petrographic thin sections show that most of the studied sandstone are moderately sorted and constituted by fine to medium grained.

The contact between grains which is an indicator of compaction was observed during petrographic studies of the thin sections. Within outcrops, the presence of cement and diagenesis marked by many load casts was observed at the contacts of the sandstones with the finest grade. The grain shapes ranged from sub angular to sub rounded. A few lithic fragments showing signs of deformation and dissolution were also observed. All types of major grain contact including concavo-convex and microstylolitic are common. Heavy minerals (imprisoned) can equally be observed in the fracture planes or simply trapped between quartz grains. Dissolution surfaces occurring in meshed contact, which are irregular joints where insoluble dissolution residue accumulates (precipitation in situ). Dissolution pressure is invoked to explain the formation of stylolite and could also account for the formation of quartz overgrowths (Fig.4G-4H).

Calcite, silica, clay minerals, and hematite are the main cement (Fig. 4) types identified in the Hamakoussou sedimentary Basin. They were apparently precipitated throughout the entire diagenetic history period (from early to late), (Fig. 5). The occurrence of two different mineral phases in the same grain, with silica or kaolinite inside partially dissolved potassic feldspar (Fig. 4C) was also noted. Quartz overgrowth over the detrital quartz grains are indicative of silica derived from the dissolution of feldspars and/or quartz. Additional isotope and geochemical data are necessary to give the exact diagenetic setting of these cements.

4.3 Porosity and permeability

Defined as the total pore space in a consolidated rock, two types of porosity can be distinguished from the facies examined:

- Primary porosity within the matrix between the different components. This corresponds to the arrangement of pores between grains and depends on the shape, rate of compaction and the grain size (Fig. 4G); the primary porosity was plugged afterwards by compaction and by silica, hematite and calcite cements.

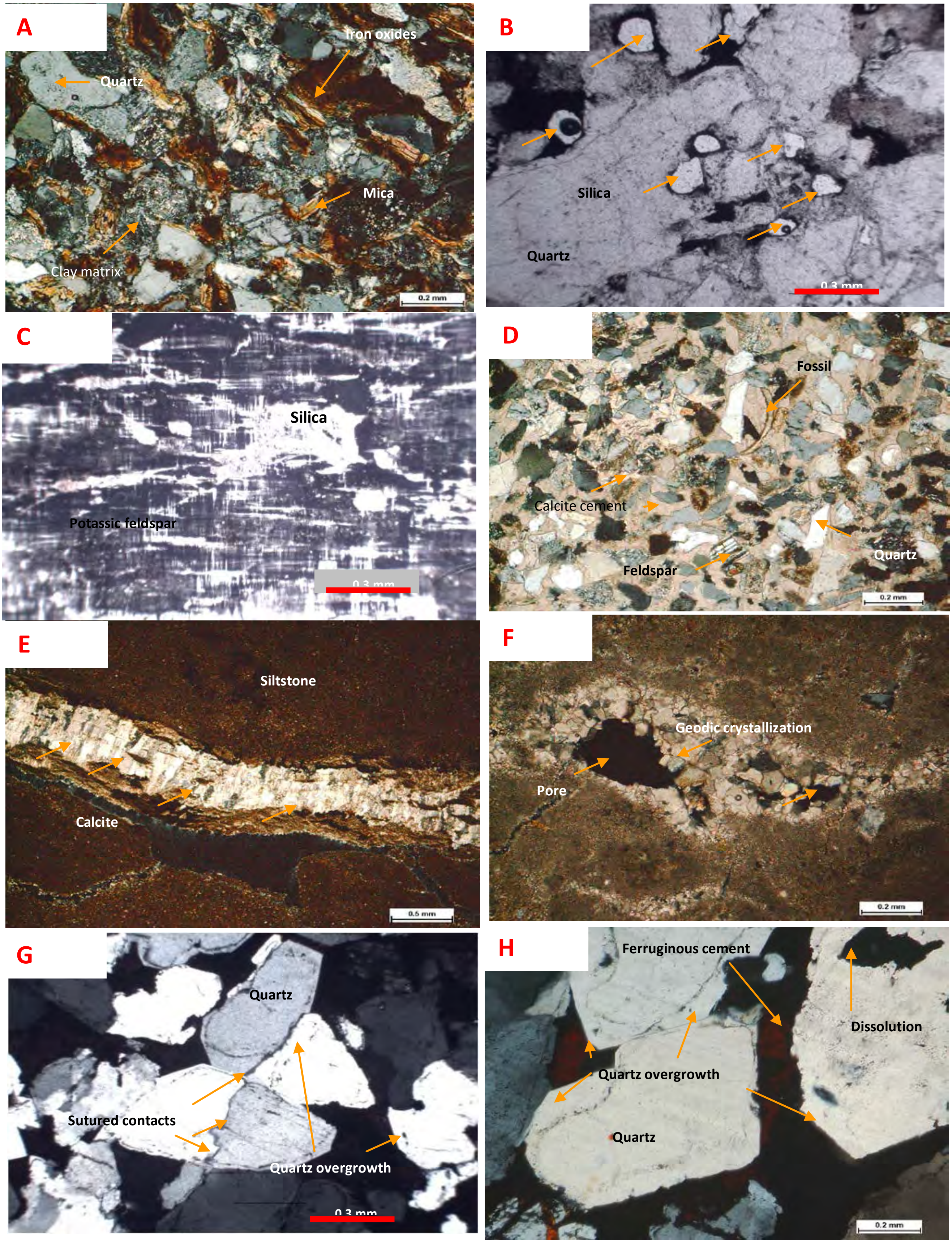

Figure 4: Thin sections micrograph. A-Hematite is another pore filling cement associated with clay matrix; mica grains observed are sandwiched between quartz grains. B- Quartz overgrowth in filling pore space. C- Intergrowth of silica in potassic feldspars. Myrrmekitisation phenomena. D- Medium to subangular sandstones

containing fossils (bivalves) and completely invaded by carbonate cement. E-The fracture have been totally filled by calcite cement. F- Geodic crystallization is observed and tends to close the pore. G - Compaction of quartz grains (triple points) in certain case shows interpenetration, sutured contacts (microstylolites), and overgrowth or nourishment phenomenon around and between detrital quartz grains. H- Formation of intergranular porosity is a result of quartz grains corrosion.

- Secondary porosity into intergranular porosity which can be associated with partial dissolution of quartz as well as the dissolution of the less stable grains like feldspar, compacted fractures, joints at the contact between detrital grains, and microcracks (Fig. 4E, 4F).

The porosity identified in this study are often blocked by the recrystallization of late fluids notably silica and calcite, and to a lesser extent, by the clogging of clays from the weathering of feldspars. The secondary porosity created by the dissolution of the less stable grains is later filled by silica and calcite (Fig. 5).

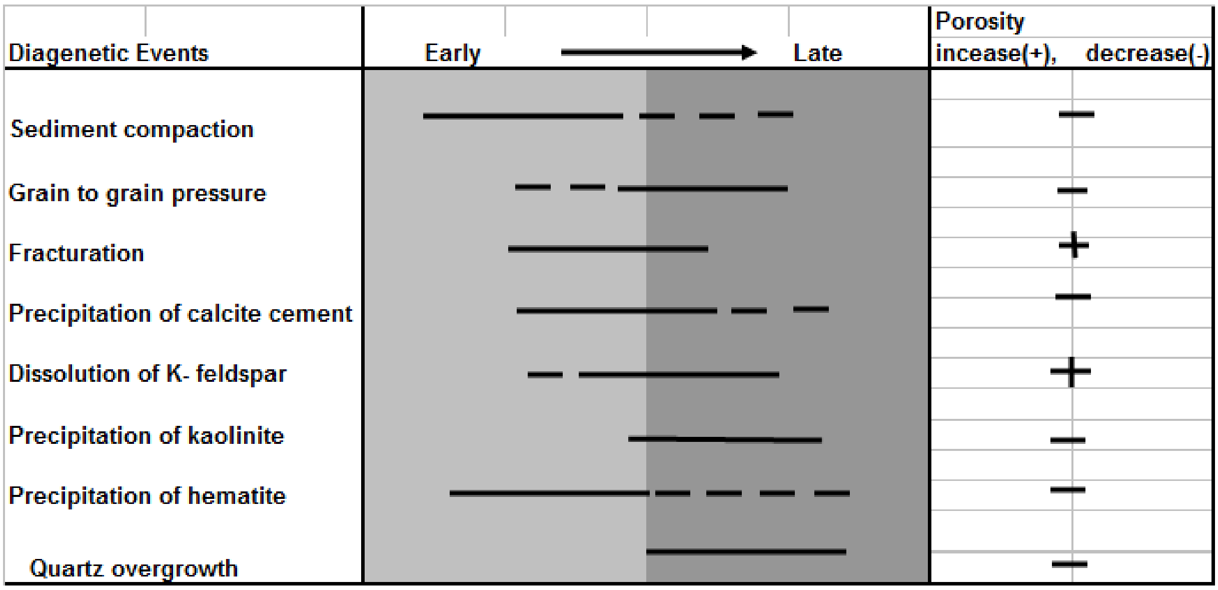

Figure: 5. The proposed diagenetic evolution of the Hamakoussou sedimentary Basin

5. Discussion and Conclusion

Sandstone facies is more common in the Hamakoussou sedimentary basin in close association with shale and volcano. The porosity of sediments generally decreases with increasing depth of burial. There exists a closer relationship between porosity and sediment structural parameters such as sorting, coarsening grain size, packing arrangement and clay content [12]. The porosity of a given depth is therefore a function of both the porosity gradient and the primary depositional porosity [13]. Microporosity is created by replacement of feldspar grains by kaolinite [14]. Compaction is marked by a reduction in the total rock space as a result of the dissolution of grains at their point of contact under constraint. The silica here originates mainly from the weathering of potassic feldspars (Fig. 2 C), (diagenetic reaction) and/or the pressure-dissolution of the contacts between grains and this further reduces primary porosity. Extensive calcite cementation into the created pore spaces contributed to the diminution of porosity (Fig. 2 D). Those diagenetic events make the porosity to be poor and pores are isolated from one another and thus not interconnected. A pressure ranging between 90 and 110 bars is required for the dissolution of quartz and the formation of stylolite [15]. This silica is mixed with iron oxides in certain samples to form the cement. The distribution of overgrowth developing on the detrital quartz grains is irregular and varies according to facies; and the border between the detrital quartz and the overgrowth is underlined by fine insoluble residue. The dissolution of plagioclase is a major source of calcite and this could equally be linked to the circulation of hydrothermal fluids relating to high volcanic activity. Compaction reduces intergranular porosity but does not affect the total volume of the rock [16]. Dissolution pressure is a deformation mechanism in rocks and a number of petrographic studies have demonstrated its importance in the compaction of sandstones during diagenesis [17, 15, 18].

Silica can be formed from many processes as shown in the following equations:

K-feldspar in kaolinite and quartz: $2K\,Al\,Si3\,O8 + 2H^+ + 2H2O = Al2\,Si2\,O5\,(OH)\,4 + 4Si\,O2 + 2K^+$ [19]

K-feldspar in illite and quartz: $3K\,Al\,Si3\,O8 + 2H^+ = K\,Al3\,Si3\,O10\,(OH)\,2 + 6\,SiO2 + 2K^+$ [19]

K-feldspar and kaolinite in illite and quartz: $2K\,Al\,Si3\,O8 + Al2\,Si2\,O5\,(OH)\,4 = K\,Al3\,Si3\,O10\,(OH)\,2 + 2Si\,O2 + 2H2O$ [20]

The phenomenon of cementation of quartz by silica which is controlled by its rate of precipitation is related more to temperature than pressure [21]. The high volcanic activity in the area definitely accounts for the presence of calcite. The presence of partially dissolved feldspars together with a poor proportion of eroded quartz and the absence of micas justify the source of silica [19, 20] in the sandstones. This explains why the facies are highly sealed resulting in the loss of two of the reservoir qualities namely porosity and permeability. This study is limited on the observations made on samples from the various profiles. It is therefore important to extend investigations using the samples of core drilling.

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