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Clay Mineralogy of the Khabour and Akkas Formations, Akkas Field, Western Iraq: Implications for Reservoir Characterization and Paleoclimatic Conditions

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Abstract: Clastic sedimentation dominates the early Paleozoic succession in subsurface section from the Akkas-1 well, west Iraq. Mineralogical investigation has revealed that the main clay components include, illite, chlorite, kaolinite and mixed layer illite/smectite, whereas, the non-clay fractions include quartz, feldspar and calcite. The clay minerals exist in both detrital and authigenic forms and in different morphologies either as scattered or filling fractures and cavities in both sandstones and shale units which may impact on reservoir characteristics of the studied rocks. Presence of these clay minerals also reflects an arid-humid paleoclimatic conditions during which these minerals were formed in addition to effect of post depositional diagenetic processes.

Keywords: Clay minerals, Paleoclimate, Reservoir characters, Paleozoic, Mining engineering

Introduction

Because clay minerals are highly sensitive to changes in structure, temperature, and pH in the weathering regime, they are frequently utilized as evidence of changes in paleoenvironmental conditions (Chamley, 1989). The clay minerals found in oil and gas exploration target rocks, such as kaolinite, smectite, illite, and chlorite, are widely distributed (Jiang, 2012). Authigenic clay minerals influence reservoir quality such as presence of chlorite (in particular) that generally enhances reservoir quality (Xi et al., 2015), whereas, illite/smectite mixed layers commonly destroy porosity and permeability (Worden & Morad, 2003).

Iraq's Paleozoic hydrocarbon systems include the Silurian Akkas Formation and the Ordovician Khabour Formation (Al-Juboury & Mazeel, 2018). The Akkas field represents the main Paleozoic hydrocarbon reserve found in Iraq to far, a lot of research has been done on it (Al-Juboury et al., 2019). One of Iraq's two confirmed Paleozoic hydrocarbon systems, the Akkas Formation has "hot shale" source rocks with sandstones that serve as reservoir rocks between intra-formational shale. The other one is the sandstone of the Khabour Formation (Aqrawi et al., 2010; Al-Juboury et al., 2021).

In the present work, alternated sandstone and shale from both the Paleozoic Khabour and Silurian Akkas formations from the Akkas-1 well, west of Iraq have been conducted for mineralogical investigations using X-ray diffraction (XRD) and scanning electron microscopic (SEM) aiming to reveal the distribution of clay minerals and discuss their impact on reservoir characteristics on the sandstone and shale in one of promising oilfields in western Iraq and to show their paleoenvironmental conditions of deposition.

Geologic History

The Arabian Plate bordered the Paleo-Tethys Ocean and comprised a part of the northern margin of Gondwana during the Paleozoic (Beydoun, 1991). Iraq is located in the upper southern latitudes of the northeastern region of the Arabian Plate, where clastic sedimentation predominates (Husseini, 1992). Western Iraq was on the stable shelf of Iraq (Figure 1). In Iraq, clastic deposition of alternating sandstones and shales dominated during the early Paleozoic (Ordovician and Silurian). These clastic units, which were deposited in shallow marine epeiric seas (Al-Sharhan & Nairn, 1997; Al-Juboury & Al-Hadidy, 2009).

As the Paleozoic era progressed, the seas' areal extent altered in response to eustatic restrictions (Beydoun, 1991). Variable bed thicknesses and lithotype associations resulted from the regress and transgression of these epicontinental shallow epeiric seas over a broad area during the Paleozoic (Konert et al., 2001). The Paleozoic successions in western Iraq have thicknesses ranging from 3 to 4 km. During the Infracambrian and Paleozoic, north-south oriented graben formations predominated in some regions, which led to heavier deposition in these grabens. Although all of these grabens were abandoned and never became fully formed rifts, they do show evidence of an extensional tectonic regime (Sharland et al., 2001).

In the studied formations, the alternating marine shales and sandstones (Figure 1) are more than 2775 meters thick (Aqrawi, 1998). The Silurian hot shales are overmature in deeper parts of SW Iraq whereas in other shallower western sections, they may still be immature. An intense "Hercynian-age" horst-graben tectonic episode exacerbated the maturation distribution differential between the shallower and deeper Silurian hot shales (Al-Ameri, 2010).

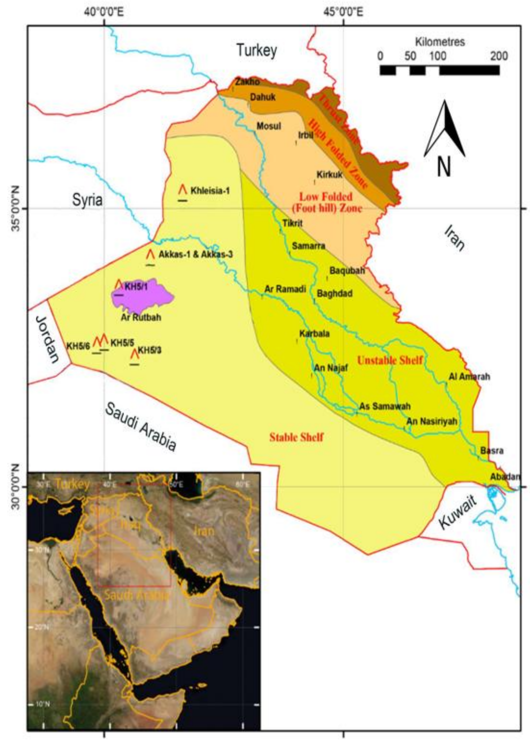

Figure 1. Structural divisions of Iraq (Buday & Jassim 1987) with the location of the studied well (B) Inset map showing countries neighboring Iraq.

Method

The X-ray diffractometer (Philips PW3710) was used to perform X-ray diffraction (XRD). The PDF/ICCD database was used to enable peak identification, and Siroquant, a commercial program from Siemens Australia, was used for Rietveld analysis and quantification. A Hitachi S-3000N scanning electron microscope was used for the analysis of the data using scanning electron microscopy (SEM) at Royal Holloway, University of London, UK.

Results and Discussion

The main clay minerals constituent of the Silurian samples includes; illite, chlorite, kaolinite and little of mixed layers of illite/smectite (Figure 2), in addition to quartz, feldspars, and carbonates (calcite and dolomite). XRD analysis for the Khabour clastics revealed that the clay minerals include; illite, mixed-layer, kaolinite, and chlorite.

The distribution of these clay minerals in the studied section (Figure 3) showed that, in the underlying Ordovician Khabour Formation, an increase in illite crystallinity is typically accompanied by an increase in illite, chlorite, and mixed-layer illite. On the other hand, the Silurian Akkas Formation shows a decrease in kaolinite clay minerals and a rise in illite and chlorite.

As burial depth and temperature rise, smectite frequently undergoes this gradual conversion into mixed-layer I-S and mica in shale deposits in sinking basins (Eberl, 1984). I-S layers are initially dispersed randomly in this reaction, and as depth grows, they progressively order. Dickite, chlorite, and the dissolution of potassium feldspars are present in conjunction with these layers (Hower et al., 1976).

Scanning electron microscopic study has revealed that several clay minerals and non-clay minerals are observed in the studied rocks including disc-shaped chlorite, fibrous illite and honey-comb illite/smectite, hexagonal kaolinite booklets, micro-quartz in detrital and with secondary overgrowth forms and calcite, mica (biotite) and pores (Figure 4 & 5).

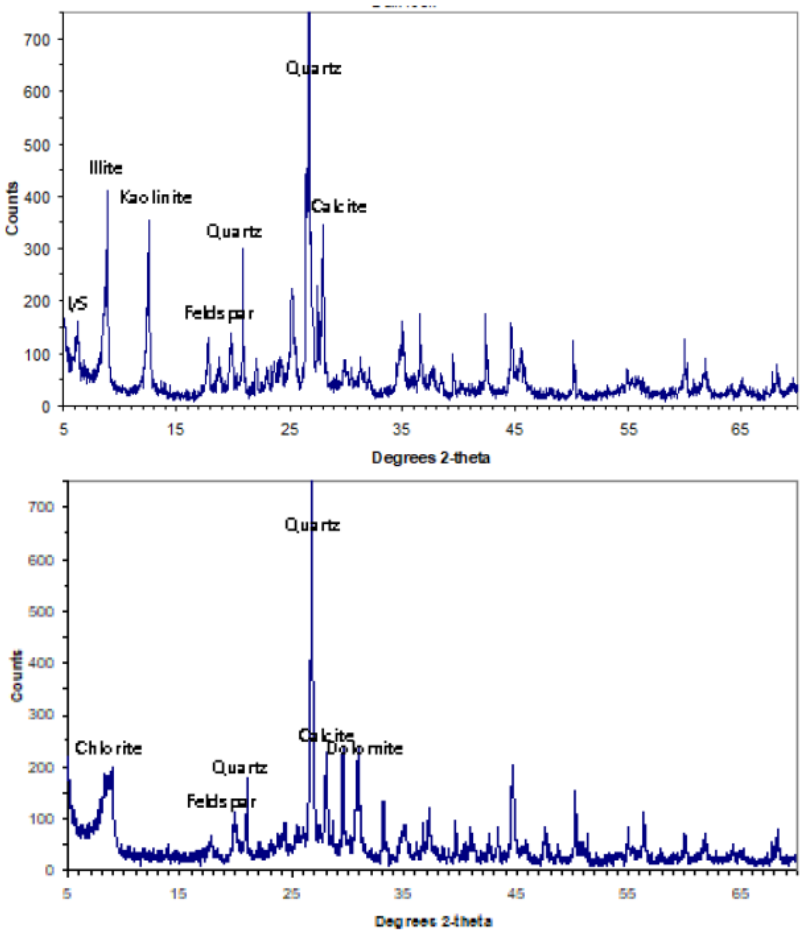

Figure 2. X-ray diffractograms of the Khabour sandstone (upper) and the Akkas shale (lower)

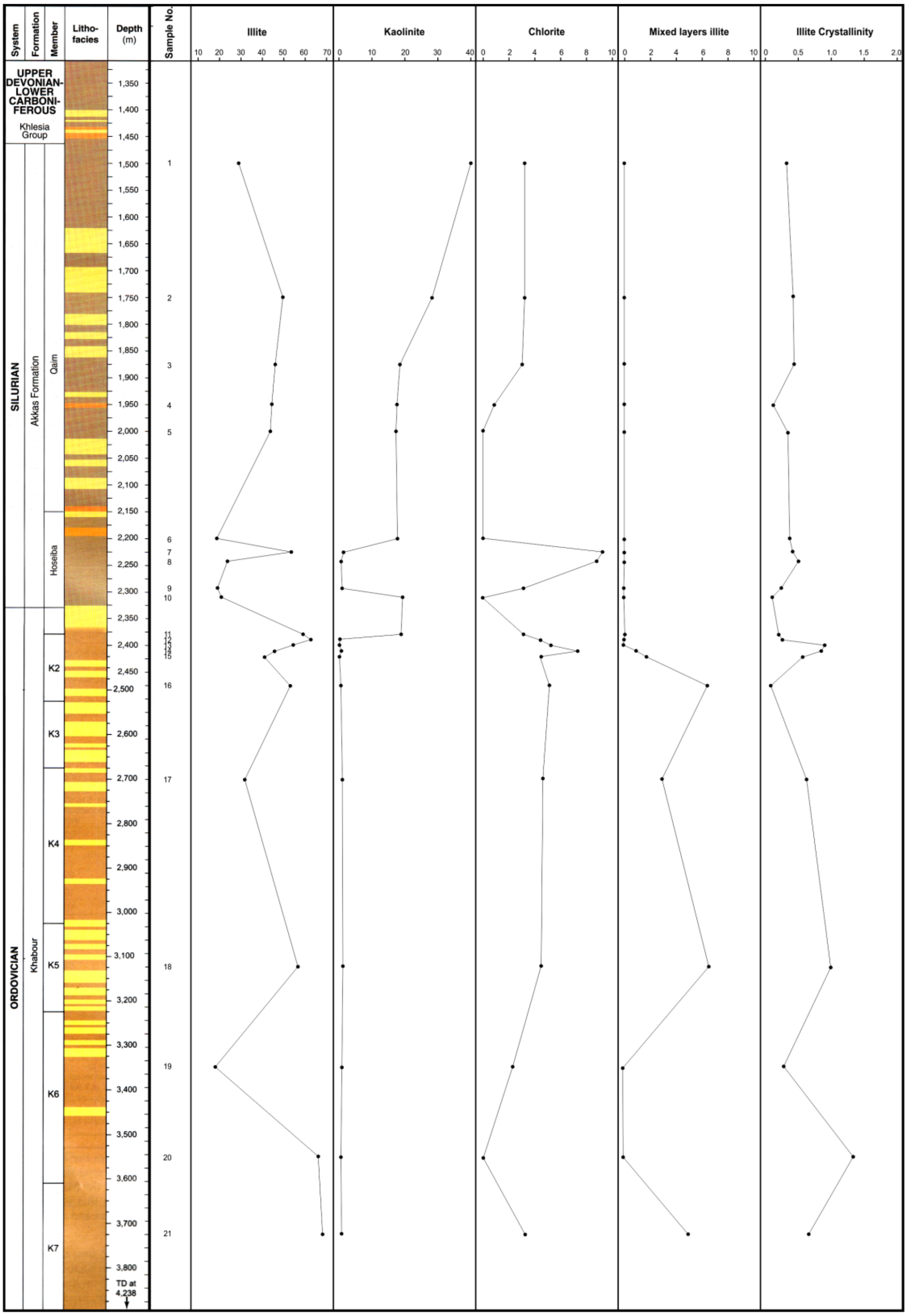

Figure 3. Distribution of the clay minerals along the lithological section in the studied formations from Akkas-1 well.

While illite and mixed-layer clays are byproducts of warm, humid climates, the presence of kaolinite is a good predictor of a humid climate (Chamley, 1989). Since chlorite typically cannot exist in cool, humid climates, its presence in sediments is a reliable indicator of a cool, dry climate (Chamley, 1989). The coexistence of illite and chlorite suggests arid climatic conditions. The SEM pictures clearly show the different morphologies of clay minerals (Figure 4).

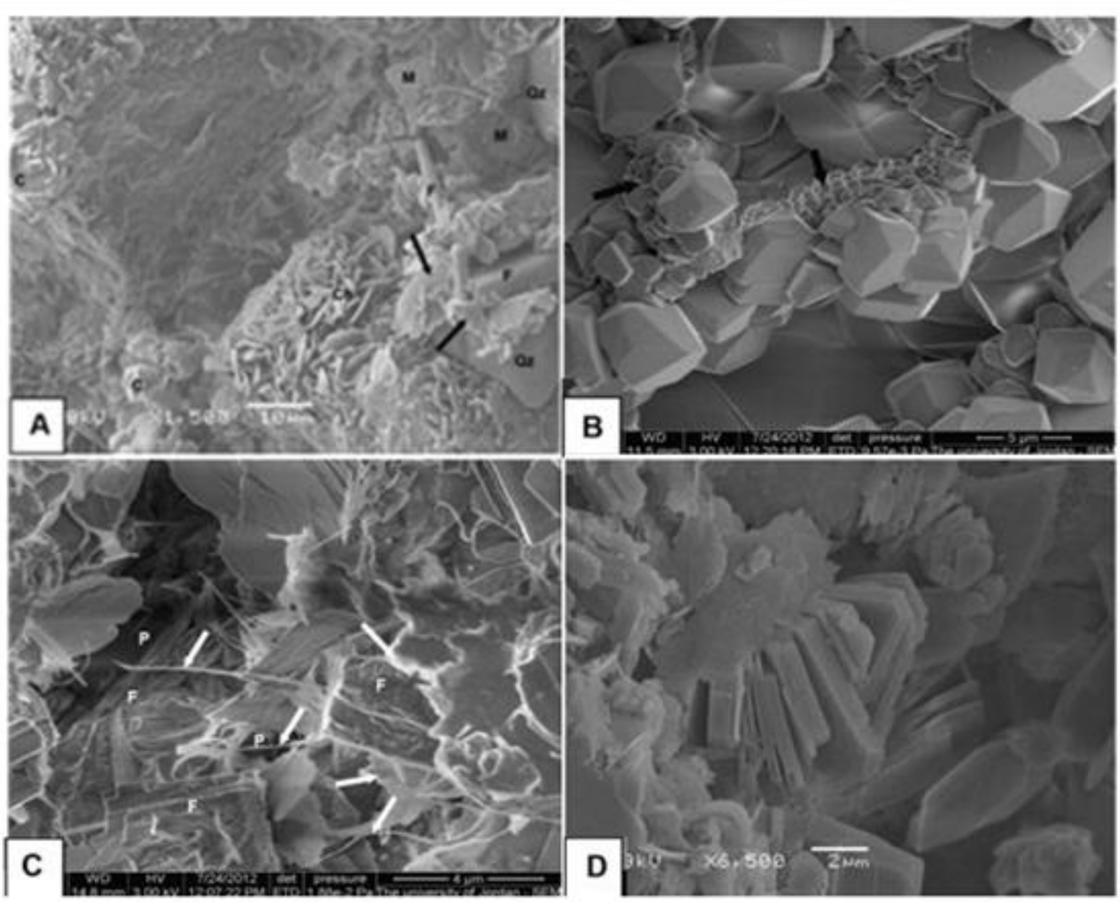

Figure 4. SEM micro images showing; A- chlorite (Ch) in a disc-shaped, carbonates (c), mica (M), feldspar (F) and, micro-quartz (Qz), B- fine to coarse carbonates (calcite) filling veins, C- fibrous illite and feldspars partly filling pores (P) D- kaolinite booklets. Samples from Khabour sandstones.

The detrital origin of the clay mineral may be indicated by the presence of kaolinite in booklets, pseudohexagonal shapes, and partially transformed hexagonal shapes into illite. Though the wispy overgrowth of illite fibers over platy detrital illite may indicate their authigenic genesis, the widespread disc-like shape of chlorite and the common flaky and fiber-like forms of illite are indicative of their detrital origin.

The sandstones from the Khabour Formation under study frequently have pore binding and pore-throat fibrous illite-smectite (I-S). Scattered carbonates and authigenic calcite and quartz also are observed. Presence of various clay and non-clay minerals filling pores or cavities has destructive effect on the porosity and permeability of the studied rocks.

The reservoir characteristics such as porosity and permeability are mostly preserved by microquartz coatings, which slow down the overgrowth of quartz by retrograding after burial. However, depending on the amount of fibrous illite present, the permeability-preserving function of microquartz is either eliminated or greatly diminished when it precipitates (Weibel et al., 2020). The authors also highlighted that the permeability is decreased when microquartz is coupled with fibrous illite, although coatings containing microquartz may assist maintain porosity and permeability.

A major factor in defining the reservoir quality of siliciclastic rocks is chlorite minerals, which are primarily found as clay coatings. They have the potential to improve reservoir quality by maintaining porosity during deep burial, but they also have the potential to worsen the situation by decreasing permeability through pore filling (Azzam et al., 2024).

Deeply buried sandstone reservoirs (>3500 m) in many sedimentary basins are regarded as high-risk prospects for geological exploration operations, such as CO_2 storage, hydrocarbon exploration, and geothermal activity. It is anticipated that quartz cementation will significantly diminish the reservoir characteristics at such burial depths (Giles et al., 1992). However, a number of investigations conducted in recent years have found that deeply buried clastic reservoirs with well-preserved reservoir quality have chlorite coats surrounding the detrital grains (Azzam et al., 2022).

By preventing quartz overgrowth, chlorite coatings can maintain porosity (Saïag et al., 2016). Therefore, estimating the quality of deeply buried reservoirs requires an understanding of the characteristics that govern chlorite coatings in sedimentary basins. In the current study, chlorite is identified in either coating of grains or in well preserved disc shaped chlorite (Figures 4 & 5).

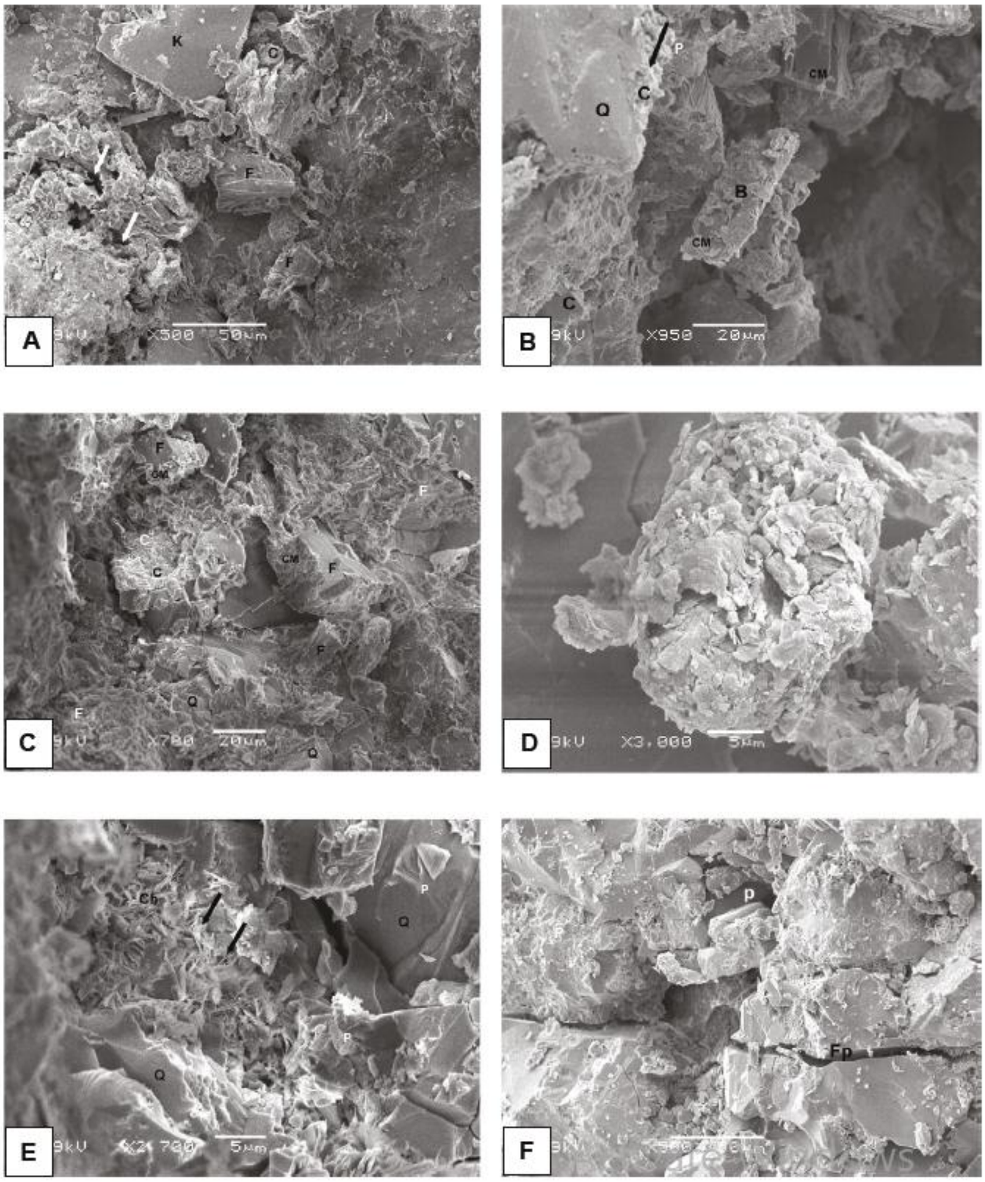

Figure 5. SEM micro-images of the Akkas sandstone displaying kaolinite (K) with dispersed calcite (C), altered feldspars (F), and common micropores (arrows). B: Quartz (Q), Mica (biotite) (B) grains dissolve, and are replaced by carbonates and clay minerals (arrows C, C, and CM, respectively). C. In carbonate cement (C), feldspar grains (F) and detrital quartz grains (Q) change into clay minerals (CM). D. A piece of corroded carbonate rock covered in clay minerals. E. Between detrital quartz grains (Q), there are illite laths (arrows) and chlorite (Ch); note the secondary quartz overgrowth. F. Microporosity (P) and fracture (Fp).

Conclusion

Evidence from clay minerals points to a changing environment during the Paleozoic succession's deposition, alternating between humid and arid climates. In general, there is a possible destructive nature on the porosity and permeability of the studied sandstone since most of clay minerals occluding pores and fractures. Several forms of clay and non-clay minerals are observed throughout the SEM current study, the presence of microquartz coupled with fibrous illite and chlorite may assist maintain porosity and permeability.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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