Lithologic Characterization and Micropore Structures of Gas Shale Strata: An example from the Midra Shale of Western Qatar

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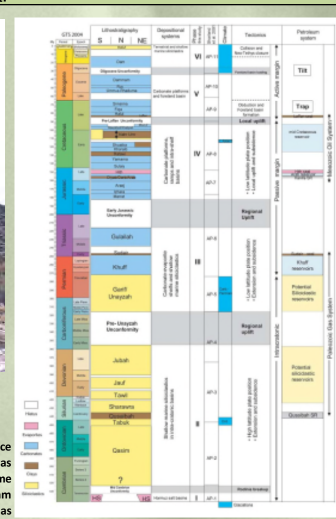
Abstract

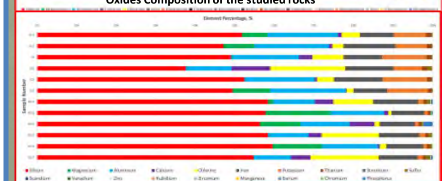
Gas shale is the future hydrocarbon reservoirs of Qatar. The Qatari geologic section has important successions of gas shale at different geologic times including the Eocene Midra shale, the Cretaceous Ratawi and Nahr Umr, and the Paleozoic Qusaibah and Unayzah formations. Shale samples were collected from the outcrops of the Midra Shale in Dukhan and Umm Bab areas. Samples were subjected to geochemical analyses using XRD and RXF. Selected samples were examined under SEM and TEM microscopes. All the studied samples contain palygorskite as the main mineral and, in some cases, the only mineral present, as indicated by X-ray diffraction patterns. XRF analysis shows that palygorskite range from ideal palygorskite (equal aluminum and magnesium content) to aluminous palygorskites where no magnesium is recorded. The most common other minor minerals are halite, quartz, calcite, and other clay minerals: illite, smectite and sepiolite. The palygorskite chain phyllo silicates result in a fibrous habit with channels running parallel to the fiber length. Transmission Electron Microscopy (TEM) images clearly show the presence of bundled lath-like crystals of palygorskite 5 to 20 nm in width and several micrometer in length. The Midra Shale was deposited in a shallow marine shelf that was subjected to clastic influx from the nearby land. So, although the Midra contains many elements that support deposition under marine conditions such as large foraminifera and shark teeth, but the presence of fully developed shale horizons indicate a mixed marine-continental depositional settings. Most of the micropores are channels associated with the palygorskite laths as can be seen from the TEM images or some dissolution pores resulted from halite and gypsum dissolution by meteoric water.

Outcrop of the Midra Shale in Dukhan Area



Geologic column of Qatar. Shale is brown (van Buchem et al. 2014).

Oxides Composition of the studied rocks



Elemental Composition of the studied rocks

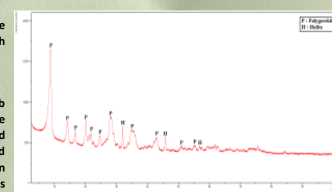
Stratigraphy and depositional history

The Midra Shale is the lower member of the Eocene Dammam Formation. This Formation forms a major part of Qatar's surface geology. It consists mainly of limestone and dolomite with subordinate amounts of shale and marls. Although the Midra was described originally as shale member, it consists of carbonate mudstone, marl, and shale. The presence of shark teeth in some horizons were considered as indication of deposition under relatively deep marine conditions. In a newly excavated sections in Umm Bab area, a section made of carbonate mud with angular, large lithoclasts of argillaceous materials. This part is interpreted as tempestite (storm deposits). The shale is present as thin laminations with pinkish iron staining alternating with white carbonate mudstone. The Midra shale was deposited in a marine shelf that was subjected to clastic influx from the nearby land. Some of these materials accumulated as thin shale beds. The tempestite may formed by ripping the newly deposited shale beds and transporting them away from the shoreline.

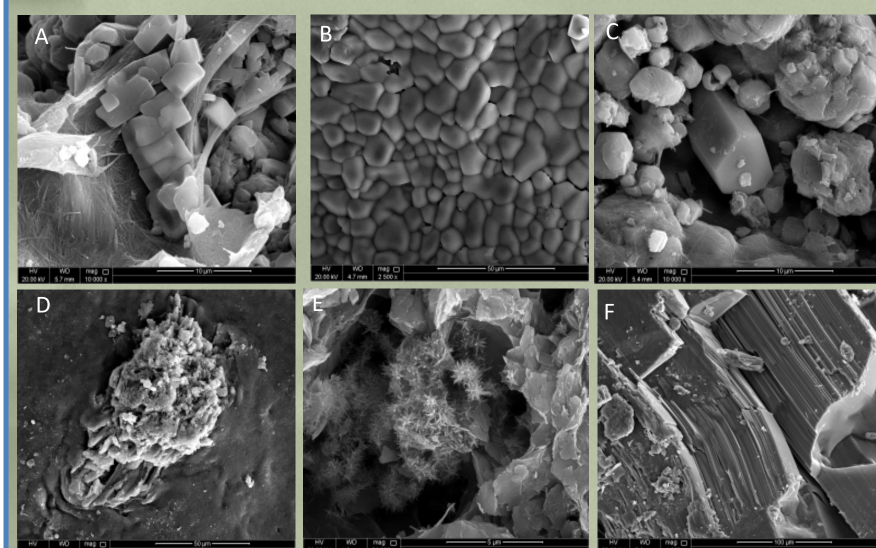
The presence of halite and gypsum within the Midra lithologies may suggest that these were gypcrete and "halcrete" formed by the evaporation of groundwater seeping upward in the relatively porous lithologic components of the Midra because of the high evaporation at the surface due to the arid climatic conditions.

Geochemistry

Samples were collected from the type locality of the formation in Dukhan area and from the newly excavated roads in Umm Bab area. These were analyzed for their chemical elements and oxides using X-Ray Diffraction and X-Ray Fluorescence. The rocks were found to consists mainly of the clay mineral palygorskite with lesser amounts of other clay minerals such as illite, smectite and sepiolite. There two types of palygorskite; the mg series and the Al series. Other non-clay minerals include calcite, gypsum, and halite. Some of the samples were examined under the Scanning Electronic Microscope (SEM) and the Transmission Electron Microscopy (TEM) to study crystal geometry and pore structures. The palygorskite is formed of long, rectangular laths with channels running parallel to these laths. Others are formed of bundled lath-like crystals of palygorskite 5 to 20 nm in width and several micrometer in length. Gypsum and halite are present as massive groundmass, but cubic halite crystals were also found. There are some fibrous, feather-shaped crystals of iron. Iron is common in most of the Tertiary sediments of Qatar.



X-Ray graph showing the main mineralogical composition of the studied rocks



Main Lithologic components

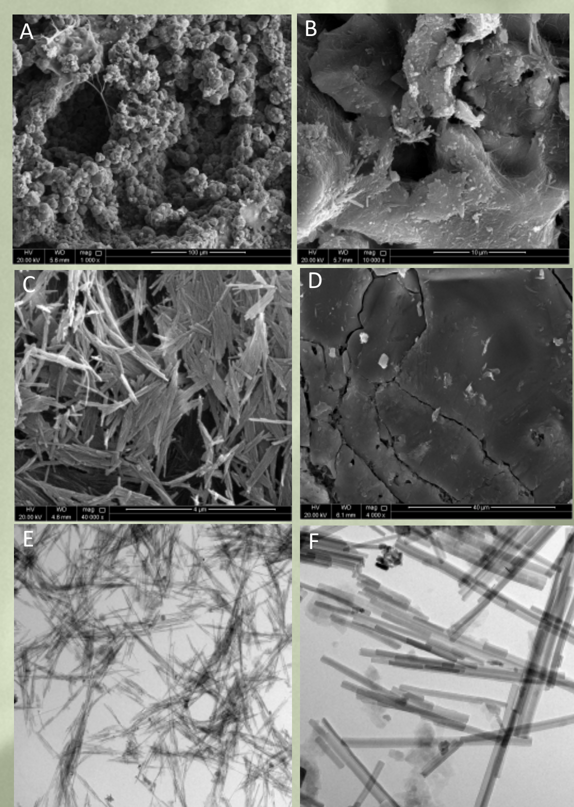
A. Well-developed halite cubes growing amid palygorskite fibers and laths. This halite is probably diagenetic in origin formed by the evaporation of the upward moving groundwater to compensate for moisture loss at the upper part of the sediments due to high evaporation under arid climatic conditions.
B. Interlocked euhedral halite crystal forming the groundmass of some of the shale sediments. These are most probably gypcrete deposited by the upward moving groundwater.
C. Feldspar crystal in the middle of calcite and clay grains. Feldspar is most probably detrital moved from the nearby land either by wind or flowing streams.
D. Iron concretion. Iron is a secondary mineral formed in local depression. Iron is common in all the Tertiary sediments of Qatar as well as in soil and it is usually associated with phosphates also
E. Fibrous crystal of iron roses filling a space between sheets of other clay minerals. These are mostly diagenetic in origin.
F. Massive gypsum crystals. These are cement precipitated by the percolating $CaSO_4$ enriched meteoric water. They are common in many of the Tertiary carbonate sediments all over eastern Arabia.

Micropores structure

The heterogenous lithology of the Midra Member, the fibrous-lath shaped structure of the palygorskite and the presence of a considerable amount of evaporites (Gypsum and halite) shaped the structure and distribution of the microporosity in the studied sediments. The major micropore types are:
(1) Dissolution micropores resulted by the selective dissolution of some of the sediment lithologies such calcite, gypsum, and halite
(2) micro and nano pores between the palygorskite laths
(3) nano pores inside some of the laths (4) micro and nano fracture of the groundmass of some of the lithologies.

Conclusions

1. The Midra Shale is the lower member of the Eocene Dammam Formation which covers the large parts of Qatar.
2. The Member consists of shale with some carbonate mudstone and marl with some large foraminifera, shark teeth and shell fragments.
3. The Midra was deposited under a shallow marine shelf that was subjected to clastic influx from the nearby land. There is a unit of tempestite (storm deposits) formed of large lithoclasts of clay floating in a carbonate mud.
4. Geochemical analyses using both XRD and XDR indicate that the studied rocks are formed of the clay mineral palygorskite with lesser amount of illite, smectite and sepiolite. Other minerals present include calcite, quartz, gypsum and halite.
5. The present evaporite (gypsum and halite) may be formed by the evaporation of the upward moving groundwater to compensate for the loss of moisture at the upper part of the sediments due to high evaporation under arid climatic conditions.
6. SEM and TEM examination of the palygorskite suggest that this mineral is formed of loosely-packed fibers and laths associated with longitudinal channels that represent important micropores.
7. Microporosity in the studied samples are either primary resulted from the loose structure of the palygorskite or secondary resulted from the dissolution of the less stable components such as evaporites or fractures due to crystal growth or tectonism.
8. The Midra Shale provide a good example of the nature of the gas shale reservoirs in Qatar.



Micropore Types

A. Dissolution pores in a micritic matrix.
B. Interface microporosity. This type of porosity results from the loose packing of different components leaving spaces between them. This may be inherited from the depositional environment or generated by later diagenetic processes.
C. Intercrystalline microporosity between the fibers and laths of the palygorskite clay mineral.
D. Microfracture porosity in a halite groundmas. These fractures are either the result of stress resulted from recrystallization and crystal growth or from tectonic stress.
E. TEM micrograph showing detailed intercrystalline porosity in palygorskite.
F. A close- up of a TEM micrograph of palygorskite showing laths of different densities (light-colored laths have less density). The light-colored laths have channel porosity.

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