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## Investigation of Petrographic and Diagenetic Properties of Asmari Reservoir Cap Rock, SW Iran

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### Abstract

Many problems in the production and development of oil fields lie in the correct and accurate assessment of the reservoir cap rock. Ramshir oil field is located 130 km southeast of Ahvaz and is one of the most important oil fields in the southwest of the country. To evaluate the petrographic and diagenetic properties, 300 thin microscopic sections were studied. According to petrographic studies, it was found that the cap rock in Ramshir oil field is composed of more evaporative sediments (mainly anhydrite with some gypsum) with some non-evaporative sediments (marl, carbonate, and bituminous shale). The most important diagenetic processes in the study area were considered to be dolomitization, cementation, compaction, anhydrite, recrystallization, and substitution. Petrographic and diagenetic studies suggest a swamp-swamp environment for this environment. Lithological changes are a sign of hot, humid, hot and dry weather during sedimentation of the cap rock of this field.

*Keywords:* Petrographic Study; Diagenetic Study; Cap Rock; Ramshir.

### 1. Introduction

Petrography is a branch of petrology that focuses on the detailed description of rocks and describes in detail the mineral content and textural relationships within the rocks [1]. In this science, stones are described with the aim of classifying and interpreting their origin [2, 3]. The most important tool for the study is the petrographic microscope [4].

For petrographic studies and finally identification of different parts of cap rock, which is one of the most important and basic studies necessary for the development of different fields, the first step is to identify the components of these sediments [5]. Therefore, in this paper, using thin sections prepared from cores and drill fragments, the petrography of cap rock is described and then the diagenesis of sulfated sediments as the main component of cap rock is discussed.

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### 1.1. Geology of the Region

The Ramshir oil field is located 130 km southeast of Ahvaz, which is located in the general northwest-southeast direction of the anticlines of oil fields in southern Iran. This field is part of the Zagros Basin, this basin is divided into different sub-basins according to the presence or absence of salt [6]. This region has several tectonic environments [7]. Oil production in this field takes place in large quantities, which is mainly composed of carbonated rock stones (Figure 1).

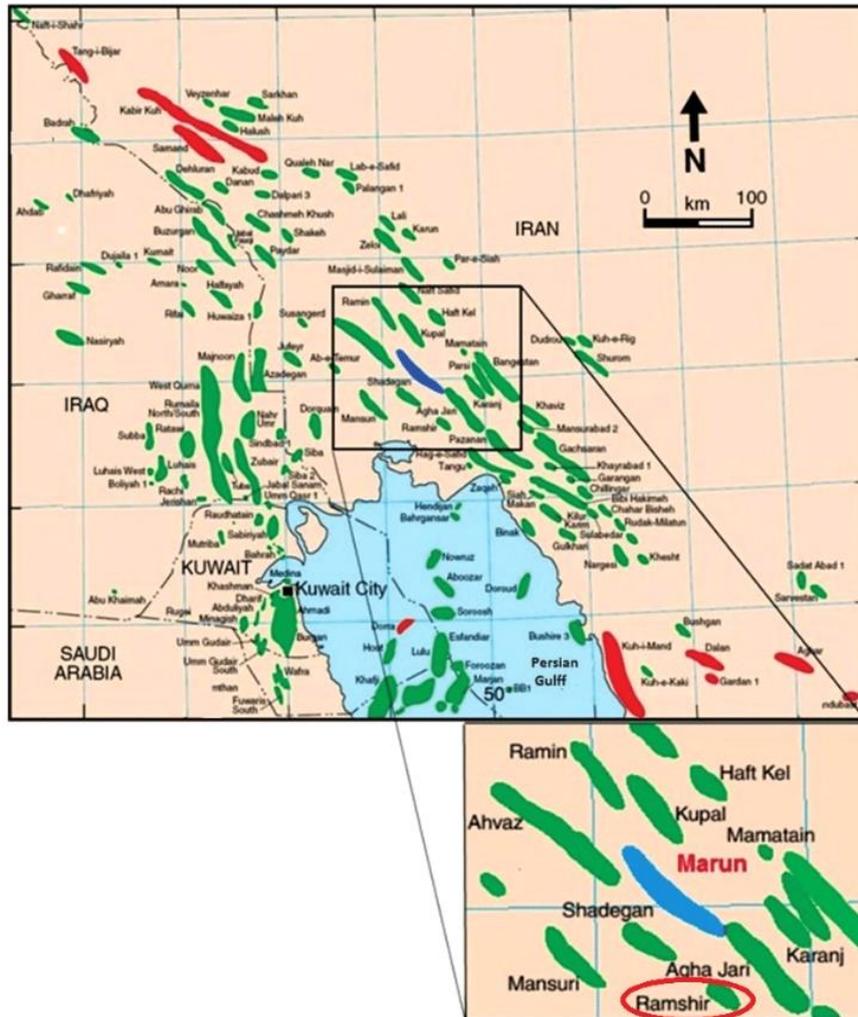


Figure 1. Geographical location of the study area in south-western Iran

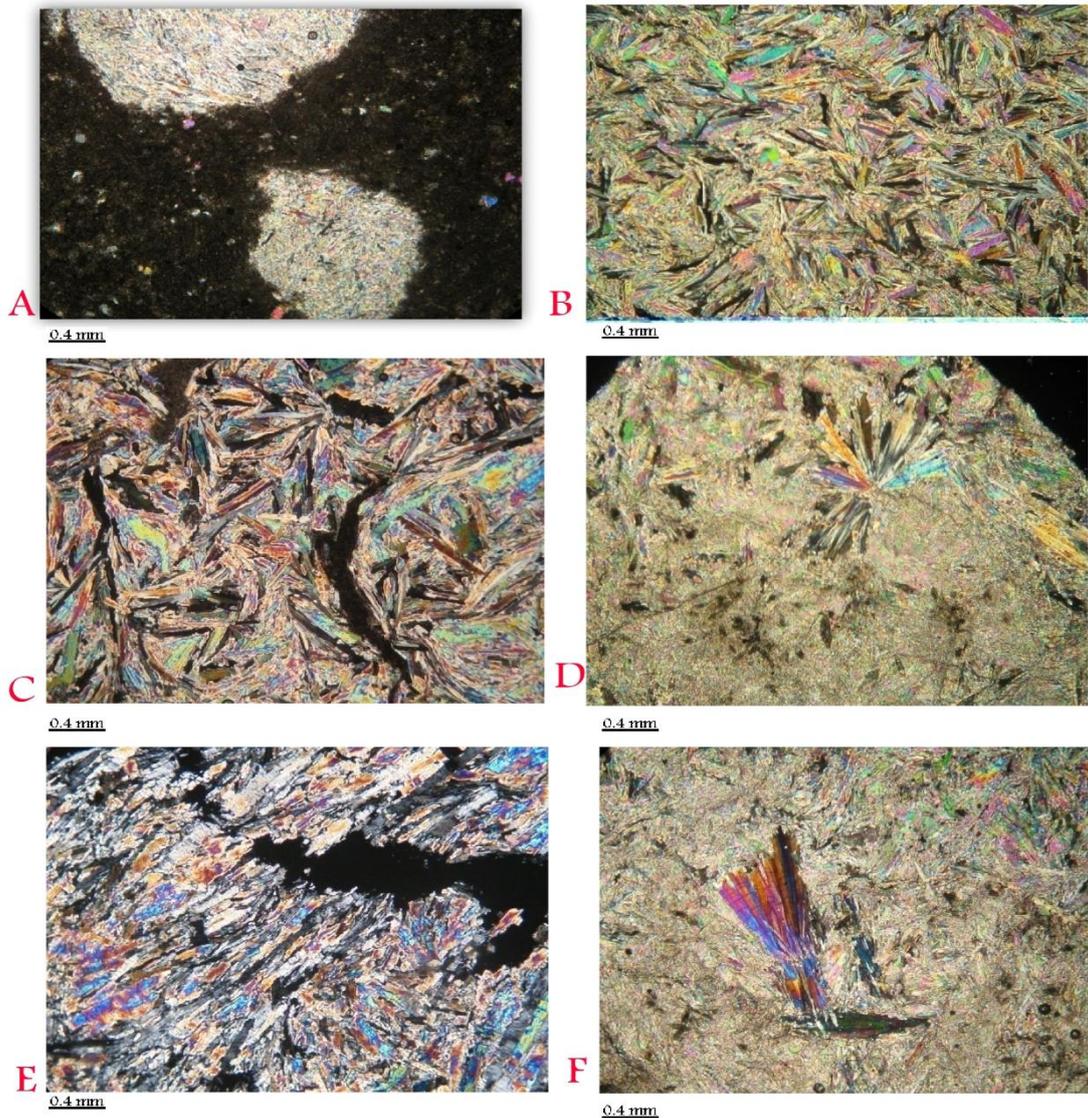
## 2. Discussion

According to petrographic studies performed on microscopic sections, it was found that the cap rock (part 1 of the Gachsaran Formation) in Ramshir oil field is more than evaporative sediments (mainly anhydrite with some gypsum) with some non-evaporative sediments (marl, carbon). Formed bituminous shale, whose lithological description is given in this section.

### Anhydrite (CaSO<sub>4</sub>)

Microscopic examination of anhydrite sediments in the Ramshir field cap rock showed that anhydrite crystals have a wide tissue diversity. This wide range of textures provides valuable information about the sedimentation and diagenetic environment of anhydrides. One of the most prominent tissues observed within anhydrite sediments is nodular tissue that shows great variation in size and shape (Figure 2-A) and other characteristics of succession growth in host sediments. Show themselves [8].

Anhydrite crystals are sometimes seen as elongated and thin anhydrite and decussate (Figure 2-B) crystals located in a matrix of fine-grained sediments. In addition to the mentioned tissues, anhydrite crystals can be seen in the cap rock radially, porphyroblastic, spherulite (blowing), coarse and sparse grains, microcrystalline and laminates in the field of sulfate or madstone (Figures 2E to 2F). The abundance of anhydrite indicates the formation in arid to semi-arid climates such as the coastal grass of the southern Persian Gulf [9].



**Figure 2. A-anhydrite nodule in a Madstone field, B-Decussate in anhydrite crystals, C-porphyroblast tissue in a field of fine-grained anhydrite, D- Radial texture in a field of microcrystalline anhydrite, E - Co-occurrence of coarse and fine anhydrite crystals next to each other, F-blowing texture in a background of microcrystalline anhydrite.**

### *Limestone (CaCO<sub>3</sub>)*

Limestones constitute the largest volume of non-siliceous detrital sedimentary rocks [10]. The limestones in the Ramshir oil field rock are Greenstone, Paxton, Waxton and Madstone according to Dunham Classification (Figures 3C, 3D, 3E, 3A). These classes are of great importance in they have stone covers and some of them are considered as guide classes (guide classes C, D, E and F). These limestones are associated with anhydrite and quartz grains and have dissolving porosities. In some madstones, the fractures are filled with sulfate, and these madstones are sometimes pseudoalite or elite, showing traces of algae, anhydrite, and sulfide. In Weston, the mold of the fossils is affected by recrystallization and the effect of compaction on the fossils is obvious. Pextones are sometimes associated with anhydrite and show traces of organic matter, and sometimes we see the phenomenon of dolomitization in Paxton (Figure 3B).

### *Dolomite*

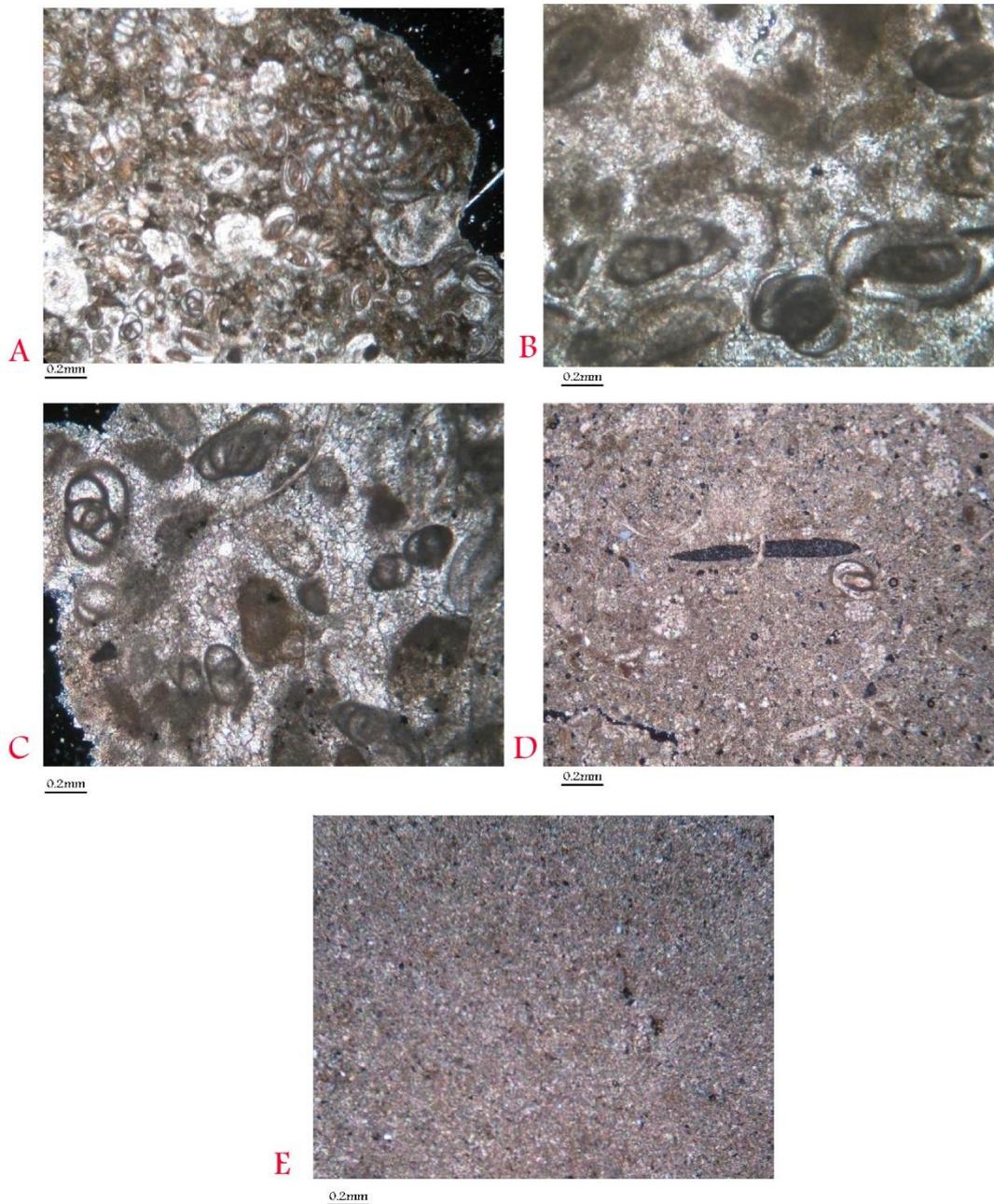
Rocks in which calcium-magnesium carbonate is predominant are called dolomite or dolostone. Fluids that are excreted during compaction or by the conversion of gypsum to anhydrite during burial are usually saturated with Ca<sup>2+</sup> [11]. Such fluids have a high Mg/Ca ratio and are able to dolomitize their adjacent carbonates [12]. Figure 12 shows an example of the dolomitization phenomenon.

**Marl**

In the cap rock of Ramshir oil field, marl sediments form the most abundant lithology after anhydrite. These sediments are mainly in the form of masses and have a uniform texture. Along with these sediments, anhydrite, gypsum, quartz particles, organic matter and sulfide are seen. Sometimes fractures and joints are seen inside them, which are mainly filled with sulfate deposits. These sediments sometimes show traces of flow and folding with fine-grained anhydrite sediments. Marl and lime cycles typically reflect cyclical fluctuations of the ancient environment. Which is related to climate change on the Milankovic scale [13]. Microscopic images of rock-covered marl sediments are shown in Figure 5.

**Bituminous Shale**

Petroleum shales usually have fine laminations consisting of alternating laminates rich in organic matter and clay matrix [14]. In Ramshir oil field, bituminous shales in the form of black to brown shales with bituminous, silt, quartz and anhydrite are considered as the guide class B and the most important key cover horizon for adaptation in the southern fields. It is the west of Iran. These shales have very fine laminae in the cores. The thickness of these shales varies from 0.5 to 3 m (Figure 6).



**Figure 3. A- Fossilized carbonate sediment (milliolite Paxton), B- Milliolite Paxton with fossil cavities filled by dolomite, C- Greenstone with milliolite fossils, D-carbonate carbonate, E-Madstone carbonate**

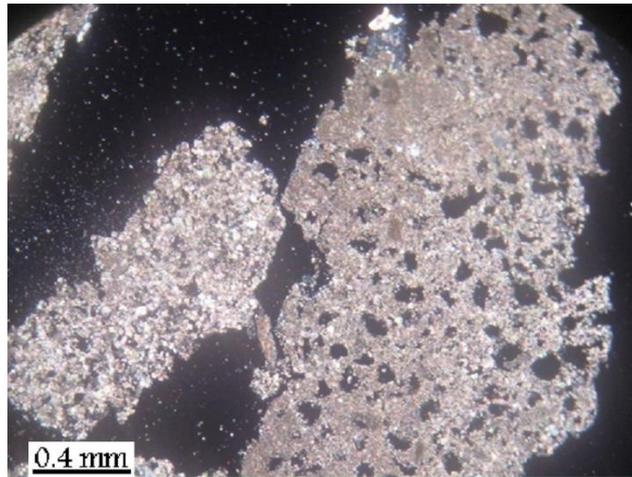


Figure 4. Dolomitization phenomenon in the studied samples

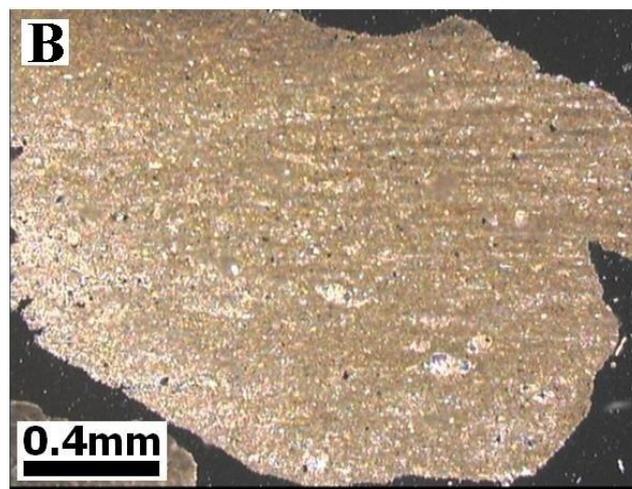


Figure 5. Microscopic images of marl sediments

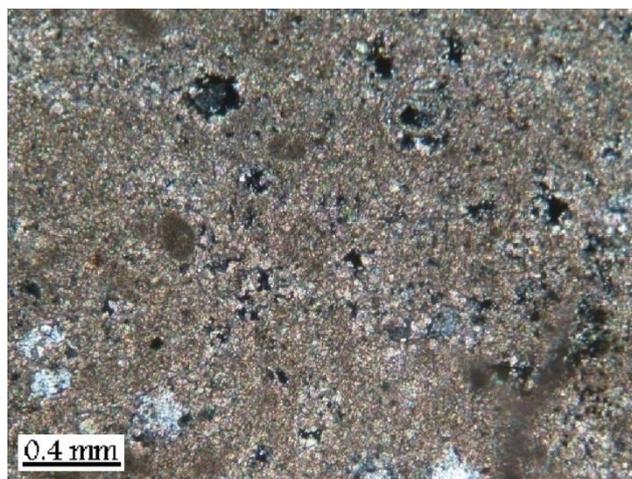


Figure 6. Microscopic image of bituminous shale in the cap rock of Ramshir oil field

### *Sandstones*

Sandstone sediments are very partially dispersed in the cap rock of Ramshir oil field. These sediments are mostly seen in the central part of the cap rock and between the guide classes B and D. These sandstones have good roundness and sorting and the diameter of sand grains varies from a few tens of microns to 0.5 mm. These rocks have dolomitic cement, microcrystalline lime and sulfate. They also have cohesive cement and physical compaction and compression dissolution are seen in their grains (Figure 7). These sediments are likely to be of sandy origin.

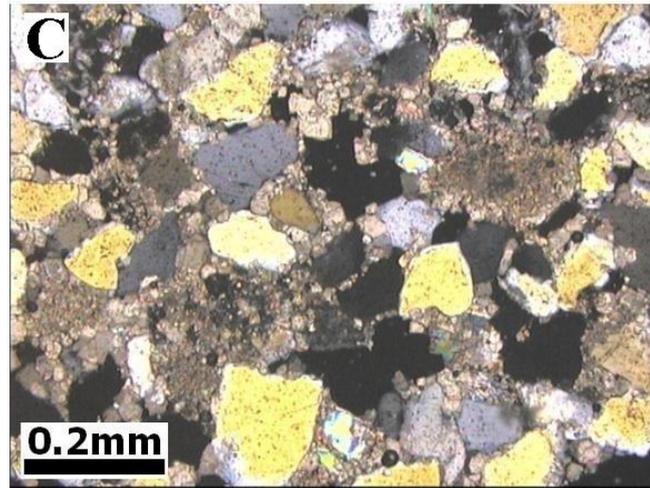


Figure 7. Sandstone with sulphated cement and co-growth

### *Sulfides*

Sulfide deposits are found in the form of impurities and in part within sulfate and marl-sedimentary sediments and are mainly between the B and E guide classes. These sediments form in clusters, clusters, and sometimes individually within the anhydrites and mantle marls (Figure 8), and sometimes in the form of haloes, enclose anhydrite nodules. These sediments are probably due to bacterial reduction of sulfates and replacement of gypsum by sulfide sediments during the simultaneous stage of deposition.

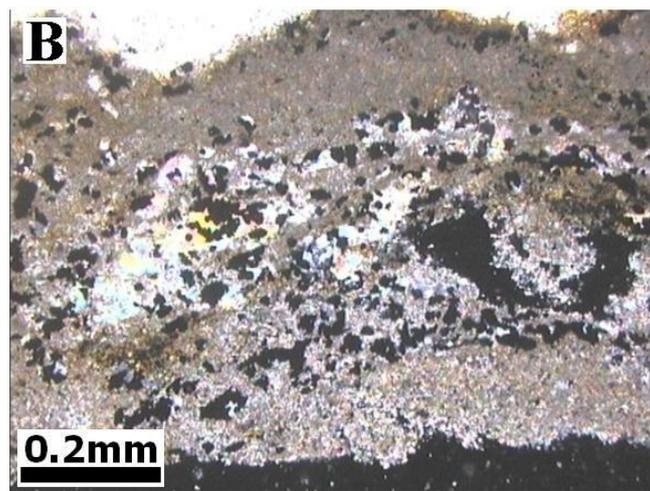


Figure 8. Scattered sulfide grains in a marl background

### *Diagenesis of Sulfates*

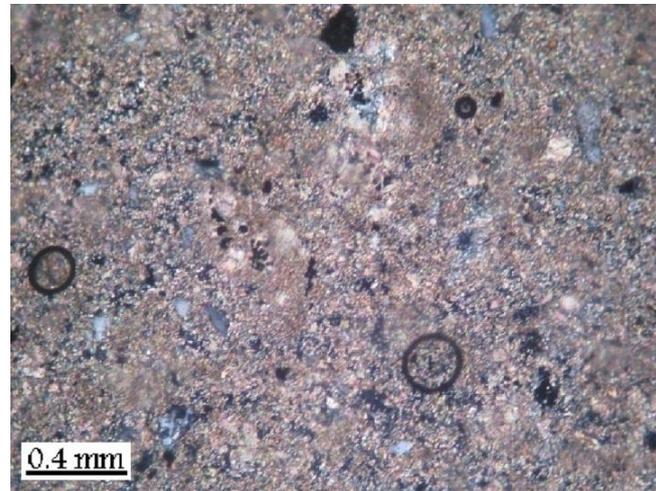
Diagenesis includes all physical, chemical and biological processes that are applied on sediments after the sedimentation stage to before the metamorphic stage [15]. According to studies, the most important processes that are effective in the diagenesis of sulfates are: anhydrification, cementation, compaction, substitution and recrystallization. The complex relationship between these processes has resulted in several petrographic and geochemical features.

### *Anhydrification*

Anhydrite is usually rarely formed in primary form, except for vegetation environments, and is mostly formed by gypsum substitution [16]. Common forms of dehydration are nodular fibers, elongated crystals of lath, and decussate, found in a matrix of fine-grained sediments. The presence of nodular and nodular-mosaic anhydrites in the cap rock (Figure 2A) indicates anhydrite simultaneously with deposition in the new evaporative medium, and indicates a stratified medium or platform margin [17]. The presence of this anhydrite nodule together with anhydrite crystals in the form of large anhydrite pseudomorphs, separate crystals and needles is one of the common forms of primary anhydrite.

### *Cementation*

Cementation in evaporitic sediments is more in the form of pseudo-forms of anhydrite after primary gypsum [18]. Primary cementation is the main mechanism for maintaining the hardness of anhydrite pseudomorphs, which protects them against increasing pressure due to overburden weight and pore water pressure [19, 20]. Substitution of primary gypsum by anhydrite pseudomorphs is accompanied by anhydrite cementation or occurs and preserves the morphology of the early gypsum [21]. These anhydrites are found in the cap rock as cement between sulfate, carbonate, and quartz crystals (Figure 9).



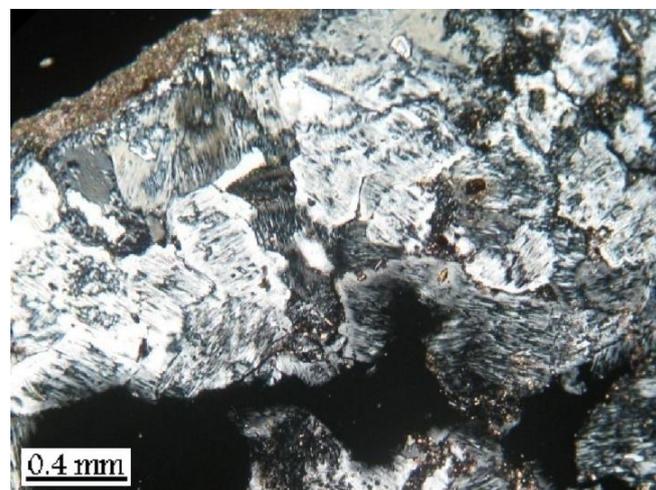
**Figure 9. Anhydrite cement inside Madstone sediments**

### *Density*

In Ramshir field, one of the most important factors controlling the fabric of anhydrides and anhydritification process is the different degree of agglomeration of primary gypsum sediments. Sediment compaction and major deformation in the primary anhydrite fabric (bending, breaking, and rearrangement) occur mainly at the time of burial. In some parts, due to the anhydrite substitution fabric and subtle deformation of anhydrite needle crystals (such as decussate in crystals), it can be inferred that the density precedes anhydrite (Figure 2B). Condensation by burial may be associated with gypsum dehydration and further reduce the stratigraphic thickness. This volume decrease occurs as a result of crystalline water escape and also the decrease in porosity due to increasing density.

### *Recrystallization*

Re-crystallization occurs in parts of the cap rock where sulfate deposits have been exposed to calcium carbonate-rich fluids as well as burial conditions [22]. This process is characterized by the presence of large, block crystals or needle-shaped and elongated anhydrite crystals that have been subjected to severe deformation and recrystallization crystallization (Figure 10). These coarse-grained crystals were obtained at high burial temperatures or by the recrystallization of fine-grained anhydrite crystals in the burial medium.



**Figure 10. Recrystallization phenomenon in the studied samples**

### Substitution and Calcification

Chemical changes in fluids may cause the dissolution of unstable minerals and their substitution by minerals that are stable under new chemical conditions [23, 24]. These diagenetic changes may be in the form of anhydrite substitution instead of gypsum or evaporation substitution by carbonates or sulfides. Pseudomorphs of calcite and pyrite resulting from the replacement of gypsum and anhydrite crystals should be due to fluctuations in solution composition and the introduction of a new solution. Dissolution of calcium sulfate and the formation of calcite nodules are highly dependent on the temperature and pressure of solutions [25, 26]. In some parts of the cap rock, we see anhydrification of fossil limestone molds that have been partially or completely anhydrified by calcium sulfate-rich fluids (Figure 11).

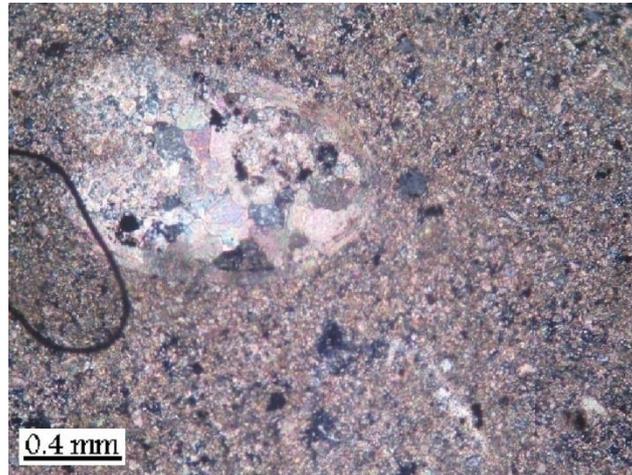


Figure 11. Anhydrification of fossil molds

### 3. Conclusions

Studies on the cap rock of Asmari reservoir in Ramshir oil field have extensive results that are presented in the following section as a case study:

- Cap rock (part 1 of the Gachsaran Formation) in Ramshir oil field is mainly composed of evaporative sediments (mainly anhydrite with some gypsum) along with some non-evaporative sediments (marl, carbonate, and bituminous shale);
- Due to the location of the rock at depths of more than 5000 feet, most of its sulfate deposits are in the form of anhydrite. This is because at these depths, gypsum is unstable and is converted to anhydrite by dehydration;
- Anhydrite is found in stone as a layer, nodule, and cement whose crystals have a wide variety of textures. This wide range of textures provides valuable information about the sedimentation and diagenetic environment of anhydrides. These textures are: nodular, interolithic, elongated and thin anhydrite crystals, decussate, radial, truncated, porphyroblastic, spherulithic, coarse-grained and sparrow-shaped, which is seen in the context of sulfate or madstone;
- Coarse-grained and sparse crystalline anhydrides were obtained at high burial temperatures or by recrystallization of fine-grained crystalline anhydrides in the burial medium;
- Anhydrides are mainly found in rocks along with other minerals, which include calcite, dolomite, Ca and Mg carbonates, fine quartz (chalcedony), pyrite, and salt. Which are mainly the result of diagenetic and substitution processes;
- Marl sediments are the second most abundant lithology in the rock cover after anhydrides. These sediments are mainly massive and have a uniform texture. These sediments show the effects of flow and folding along with fine anhydrite sediments and have fractures and joints that are mainly caused by sulfate deposits being filled;
- Bituminous alloys are black to brown alloys containing bitumen, silt, quartz, and anhydrite. These shales have very fine laminae in the cores. These shales have a small thickness but are present in the whole field, which indicates uniform conditions at the time of deposition in the whole field, so they are considered a guide class B;
- The most important processes that are effective in the diagenesis of sulfates are anhydrification, cementation, compaction, substitution, and recrystallization;

- The presence of nodular and nodular-mosaic anhydrides in the rock envelope indicates anhydricification at the same time as deposition in the new evaporative medium and is a sign of vegetation environment or platform margin;
- Anhydrides are found in cement in the form of cement between sulfate, carbonate and quartz crystals and protect them against increasing pressure due to overburden weight and pore water pressure;
- Substitution processes in rock cover are mainly in the form of anhydrite substitution instead of gypsum or evaporation substitution by carbonates or sulfides;
- Concentration of rock cover evaporation by burial may be associated with gypsum dehydration and further reduce stratigraphic thickness. This volume decrease occurs as a result of crystalline water escape and also the decrease in porosity due to increasing density;
- Recrystallization can be seen in parts of the rock cover where sulfate deposits have been exposed to calcium carbonate-rich fluids and burial conditions. This process is characterized by the presence of large, block crystals or needle-shaped and elongated anhydrite crystals that have been subjected to severe deformation and recrystallization crystallization. These coarse-grained crystals were obtained at high burial temperatures or by recrystallization of fine-grained anhydrite crystals in the burial medium.

## 4. Declarations

### 4.1. Author Contributions

S.A., S.P. and A.M contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

### 4.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

### 4.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

### 4.4. Institutional Review Board Statement

Not applicable.

### 4.5. Informed Consent Statement

Not applicable.

### 4.6. Declaration of Competing Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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