Significance of the evaporite occurrences in the Hawasina Window, Oman Mountains

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Abstract

In 2006 and 2007 geologists from MOL Plc. conducted field trips in the central Oman Mountains in order to describe and evaluate the potential hydrocarbon systems; to reveal source-, reservoir- and seal rocks and to outline possible hydrocarbon bearing structures. Bedding, cleavage, fold and fault data were recorded during the field work. Numerous samples were collected for the organic geochemical, rock mechanical and thermochronological measurements. During the fieldwork we observed several occurrences of small gypsum diapirs in the Wadi Dil and Wadi Hawasina area; these evaporite bodies rise from beneath the Hawasina Nappes. Structural analysis of the wider area suggests that they belong to the Palaeozoic (Infra Cambrian or Permian) of the underlying Arabian Platform or to the Late Cretaceous sequences. In all the three cases the occurrence of the evaporites has a crucial role in the hydrocarbon systems of the area and points to the existence of the Autochtonous sequence beneath the oceanic nappes. This shows the possibility to explore the classical petroleum systems of the Arabian Peninsula below the Oman Mountains.

Összefoglalás

Az ománi Hawasina-ablak területén található evaporit előfordulások jelentősége
A 2006-2007 években a MOL Plc. geológusai terepmunkát végeztek az Ománi-hegységben található Hawasina tektonikus ablak területén. A munka célja a terület szénhidrogén rendszereinek megismerése, a lehetséges anyakőzetek, tározó-, és zárókőzetek feltérképezése és mintagyűjtés ezekből további laboratóriumi vizsgálatok céljára. A munka során tektonikai adatokat, rétegzési, palássági, redőződési és törési irányokat is felmértünk, melyek a lehetséges tároló szerkezetek lokalizálását segítik elő. Számos minta került begyűjtésre szerves geokémiai, kőzetmechanikai és termokronológiai vizsgálatokra. A térképezés során több kisméretű gipsztestet fedeztünk fel a Wadi Dil és a Wadi Hawasina területén. Ezek elhelyezkedése, rétegsorban elfoglalt helye és a környező triász korú radiolarit rétegekkel való érintkezés módja arra utal, hogy ezek a gipsztestek diapírszerűen, a mélyebb rétegekből préselődtek a fel-

színre. Több lehetséges forrást is megjelölhetünk, ahonnan ezek az evaporitok származhatnak. Az Arab-tábla autochton rétegsorában két jelentős evaporit horizont is ismert, az első a késő prekambriumi korú Ara Formációban, míg a második a perm korú rétegekben. További lehetőségként felmerülhet az evaporit késő kréta keletkezése is, ebben az esetben az autochton rétegsorának tetején helyetfoglaló gipsz kiváló csúszófelületet képezhetett a takaróképződés során. Bármelyiket is feltételezzük a fenti három esetből, az evaporitok előfordulása kulcsszerepet tölt be a terület szénhidrogén rendszereiben, és egyúttal bizonyítja az autochton rétegsor jelenlétét a Hawasina ablak alá tolt helyzetben.

Introduction

The Oman Mountains lies on the north-eastern corner of the Arabian Peninsula. It is classically regarded as a type example of an ophiolite overthrusted passive continental margin of the Tethys Ocean. Glennie et al. (1973, 1974) produced the first comprehensive stratigraphy of the whole mountain range. They described the main tectonic and stratigraphic units of the area. Due to their work the Oman Mts. contains (from top to bottom) obducted ophiolites (Semail Nappe) and sheared-off oceanic sediments (Umar, Hamrat Duru and Sumeini nappes) above the Arabian platform (Fig. 1 and 2). The underthrust Arabian Platform is exposed in two major antiformal windows; these are the so called Saih Hattat and Jebel Akhdar windows. A third window, i.e. the Hawasina Window exposes the oceanic nappes.

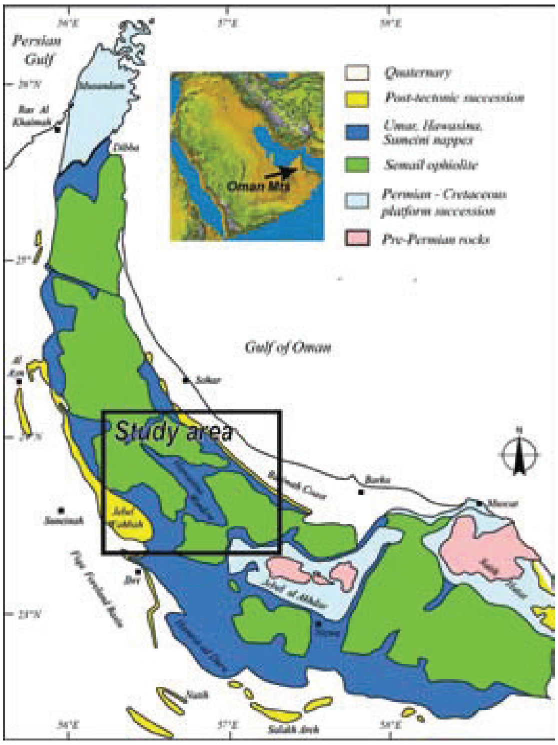

Figure 1. Location of the Hawasina Window area in the Oman Mountains, Arabian Peninsula. The main tectonic units are indicated by different colours. The Hawasina Window is a tectonic window, where the older oceanic nappes of the Hamrat Duru series outcropping from below the younger Semail Ophiolite.

The well known hydrocarbon systems of the Arabian Platform are abundant and effective in the Oman region. From this rise the question of the existence and effectiveness of these hydrocarbon systems in the underthrust segments of the Arabian Platform below the Oman Mountains. The Hawasina Window is a positive, antiformal structure, covered by the well sealing oceanic sediments of the Hamrat Duru Group; therefore it is the best feature to evaluate this concept. Fieldwork was conducted to reveal the potential hydrocarbon systems of the area and to describe the deformation style and potential hydrocarbon bearing structures below the Hawasina Window. During the fieldwork we found several differences between our observations and the previously published geological maps (Villey et al. 1986). One of the most important result was the existence of small evaporite (mainly gypsum) diapirs in the middle of the Hawasina Window around the Wadi Dil and Wadi Hawasina. These evaporites has a key role in the understanding of the general build up of the Hawasina Window and points to the possibility of the existence of the Arabian Platform sequence beneath the oceanic cover nappes.

The general build-up of the Hawasina region

In the Hawasina Window (Fig. 1) three major units, three nappes can be classically differentiated: Sumeini, Hamrat Duru and Umar units (see Fig. 2A). These are composed of oceanic volcanites and sediments (first Lees 1928, then e. g. Allemann & Peters 1972, Glennie et al. 1973, 1974, Béchennec 1988, Béchennec et al. 1988, 1990). The Sumeini Unit – the lowermost identified nappe unit – is composed of the mainly calcareous and shaly slope-sediments of the Arabian Plate (Glennie et al. 1974, Graham 1980a, b, Béchennec

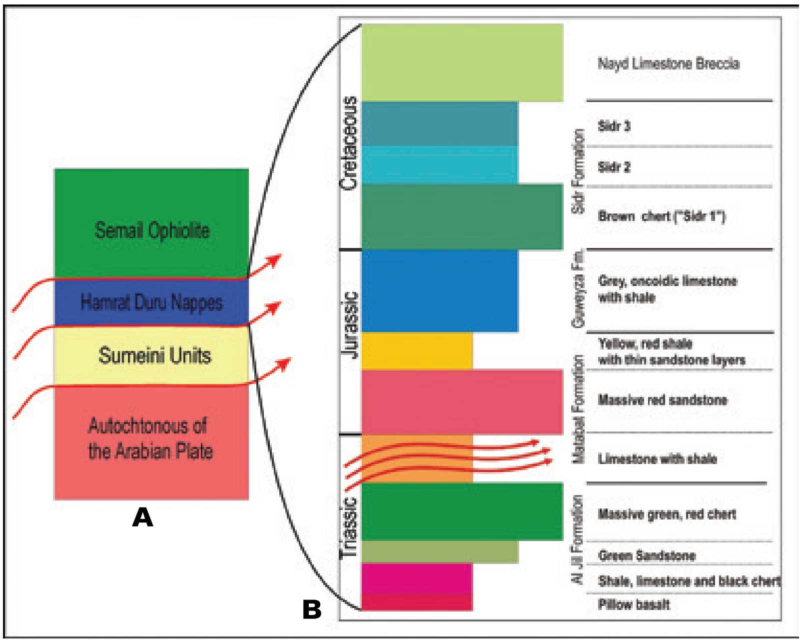

Figure 2. A) Main tectonic units of the Oman Mountains; B) Schematic stratigraphy of the Hamrat Duru Units (figure is not to scale).

1988, Béchennec et al. 1988, 1990). The sediments of the Hamrat Duru Unit are deposited in a starved oceanic basin; this was the subbasin of the Neo-Tethys Ocean (e. g. Glennie et al. 1974, Graham 1980a, b). The lithology of the Hamrat Duru sediments is very variable: even in the same litostratigraphic unit we can separate fine and coarse calcareous, cherty, shaly and sandy members (Fig. 2B). The Umar Unit – tectonically on top of the Hamrat Duru formations – is the most heterogenous unit; following several paleofacies-reconstruction works (Béchennec 1988) these deposits are derived from and around within-oceanic volcanic islands with atoll-like reefs of several ages (Permian and Triassic). The uppermost tectonic cover, the Semail Ophiolite is the obducted oceanic lithosphere of the Neo-Tethys Ocean (e. g. Glennie et al. 1974 and Searle et al. 1980).

Stratigraphic and tectonic position of the evaporites

Evaporite bodies were mapped in two different stratigraphic and tectonic positions. 1) Right below the Hamrat Duru Nappes in the Hawasina Window and 2) beneath heavily folded Sumeini exposures in the Qumayrah half-window.

1) In the middle part of the Hawasina Window a greyish, soft rock surrounded by its pinkish, purple, ocker alteration zone is exposed. Strong sulphurous smell and many gypsum veins and smaller gypsum and sulphur crystals indicate that the grey and soft rock is in fact microcrystalline gypsum. The region is gently uplifted with respect to its neighbourhood; the pinkish oxidized gypsum is topped by radiolarite and shale.

The contact cannot be sedimentary for two reasons: first, oceanic sediments are very rarely underlain by evaporates, and secondly, clearly discordant contacts are recognised. These are always in the form of broken, upwards dragged layers of Triassic radiolarite (Fig. 3C and D). Gypsum body is always broader downwards and is found in the core of regional folds (Fig. 3A). The contact can be qualified as "intrusive"; i.e. gypsum protrudes from below and uplifts the radiolarite above. The internal structure of the gypsum intrusions is marked by xenoliths embedded in soft gypsum and by centimeter thick gypsum veins. The xenoliths-clasts are often aligned and arranged into parallel sets. These are marked by an incipient subvertical cleavage and by the long axis of the non-gypsum clasts. From a fortunate exposure in the junction of wadi Hawasina it is clear that the cleavage and alignment of the xenoliths marks flow paths (Fig. 3B). In all the gypsum comes from below the Al Jil Formation and intrudes them, flows upwards. It forms fingers in the order of 100 m diameter. The gypsum fingers should be provisioned from a greater evaporite stock at depth. This should also contain halite and cover salts, because several gypsum finger samples tasted halite/silvine.

The stratigraphic position of the evaporite fingers was controlled by collection of clasts from the gypsum ash. In several exposures smaller and bigger diameter clasts or fragments of layers were found within the soft matrix. The composition of the clasts ranges from purple polymict sandstone to red shale, white quartzite, conglomerate,

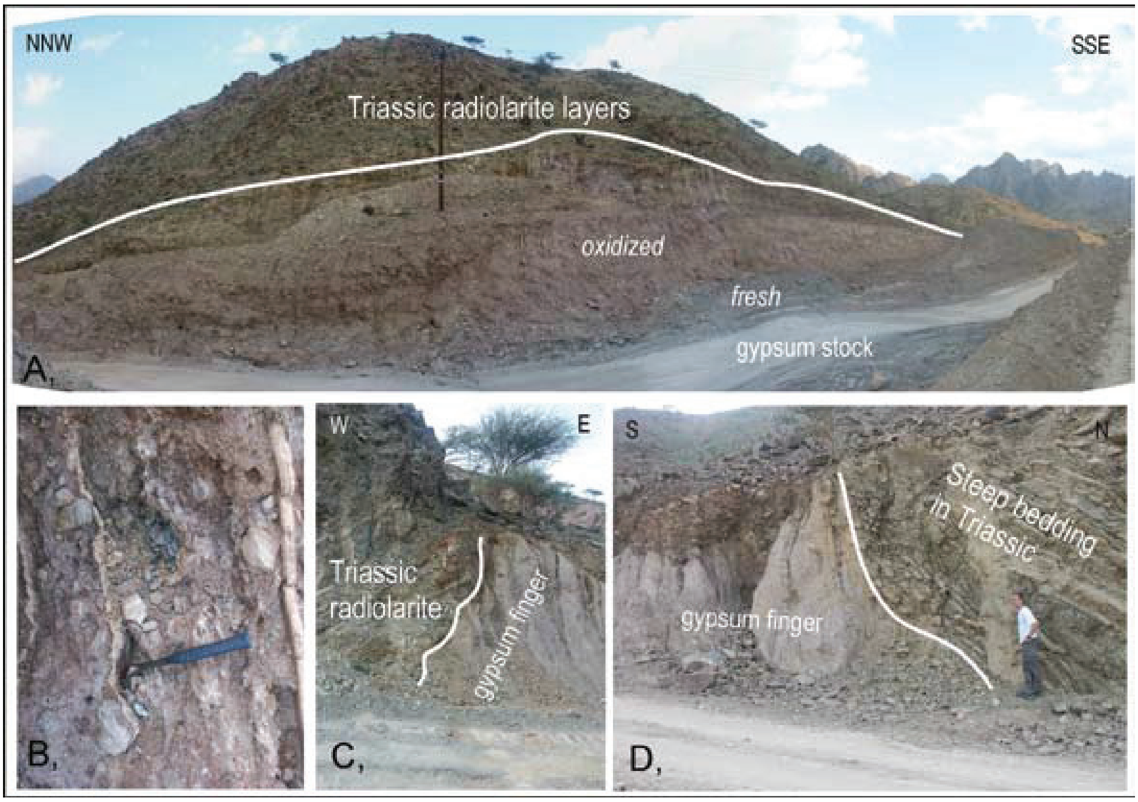

Figure 3. Outcrops of the gypsum stocks in the Wadi ad Dil. A) Panoramatic view of the largest gypsum finger; B) Clasts of different lithologies in the gypsum ash, aligned along surfaces indicating streamlines of the rising evaporite. C) and D) Steep contacts of the gypsum with the overlying Triassic radiolarites (note the dragging upward of the chert layers).

grey limestone, black-white banded chert and black, oolithic limestone. These latter were partly coupled with black, sulphur-rich clay. Black clay with sulphur was also found as individual blocks. Frequently rounded individual pebbles were also discovered. One of these was composed of coarse grain granite.

2) Another evaporite occurrence was visited at the Qumayrah half-window. There the stratiform-like evaporite is stratigraphically above the Qumayrah (Sumeini) marl and potentially below Hamrat Duru units. It is important to know, that because of complex double folding, it is also geometrically beneath the Sumeini. Gypsum forms 20-50 cm thin layers with interlayered variegated sandstone, shale and black, thinly layered laminated limestone. No fossils were found so far. The structural position of this evaporite is quite strange. On one hand, it lies geometrically in lower position, in the core of a sheared syn-cleavage fold, overturned to the west. A smaller thrust affects the overturned limb and puts the normal limb with a row of stratiform gypsum exposures on top of the overturned limb. However, this fold occurs on the fully overturned limb of an earlier tight/isoclinal fold of the Sumeini succession, so the youngest formation is in direct contact with the evaporite. This raises the possibility of the evaporite being Late Cretaceous in age. This might be possible, although not supported by any neighbouring occurrence. The eventual Late Cretaceous evaporite deposition might be due to the emersion ahead of the advancing nappes.

Problem of origin and timing

A quick interpretation of the collected clasts suggests an old, Cambrian – Late Precambrian or alternatively Early Permian age for the evaporite succession, because these are the two age intervals, when large amounts of evaporites were deposited in the near surroundings. Miocene evaporites were ruled out because of the geometric reasons. No identified Mesozoic rock of the Autochtonous succession was found as clasts. Petrographical investigations on thin sections (Al Harty et al. 2007) were performed from sandstone and carbonate clasts and control samples of Matabat sandstone of Hamrat Duru unit. Petrographically sandstone clasts in gypsum were rich in feldspar; a feature not known in Hamrat Duru sandstones but common in Precambrian, Cambrian and Permo-Carboniferous sandstones in Oman. Some clasts had fluiviatile or aeolian facies, again not conformable to deep marine or turbiditic facies of the Hamrat Duru clastic formations. Aeolian facies in particular are well known in the Amin sandstone of Infracambrian age of Interior Oman. Fluviatile facies may correspond both to Precambrian-Cambrian and Permo-Carboniferous clastic rocks. Thin section interpretation of some dark carbonates suggests microbial algal lamination, common in Ara Formation of Infracambrian age. Oolithic limestones with dark shale interbeds also suggest Precambrian Kharous or Hagir Formations. Alternatively, these may occur in Permian shallow marine deposits as well. No fossils were found so far.

In summary, many studies of clasts or the position of the evaporite itself suggest that the gypsum fingers rose from a larger evaporite body of possible Late Precambrian – Palaeozoic or Late Cretaceous age.

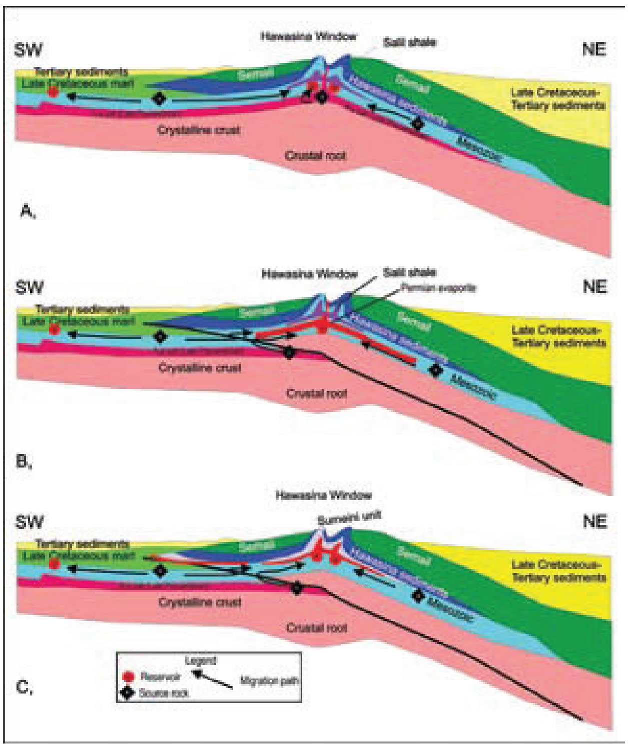

Figure 4. Structural models explaining possible tectonic position of the evaporite. A) Evaporite rising from below the Autochtonous series, it implies the Late Precambrian age of the gypsum; B) Evaporites rising from the Palaeozoic sequence of the Autochtonous of the Arabian Table, it implies the Permian age of the salt; C) Gypsum acts as a detachment horizon on the top of the Autochtonous sequence, in this case the evaporite is possibly of Late Cretaceous, Permian of Infra Cambrian age. (sections are not for scale)

Interpretation – HC accumulation model in the light of tectonic position of the evaporites

Although the extent and age of this evaporite body are not known yet precisely, three alternative positions seem plausible based on field indications. These are best explained by the generalized cross sections (Fig. 4).

Our first model supposes the evaporite may rise from a deeper level of the Autochtonous; this level may be of Infra-Cambrian (i.e. Ara) age (Fig. 4A). Clasts within the gypsum plugs may support this interpretation. In this case an underthrust portion of the Late Proterozoic Fahud Salt Basin could exist below the Hawasina culmination. This play invokes source rocks at Natih (Cretaceous) and late Precambrian levels, and potential reservoir rocks in the Permian-Triassic dolomites. The effective seal would be the Salil shales (Lower Cretaceous).

The second theoretical position (Fig. 4B) of the evaporite is supposed to be Permian and located within the Autochtonous. In this case the detachment below the Sumeini units is the Salil shale. The source rocks are the same as above, but only the Permian dolomites can be the reservoir, as the evaporite layer forms a seal on top of them.

As a third variant, the evaporite may be also located right beneath the Sumeini unit (Fig. 4C). In this case this relatively thin detachment horizon separates the Autochtonous and the Sumeini nappes. Originally this evaporite might have been a stratigraphic term at the basis of Sumeini succession or at the highest (i.e. Late Cretaceous) position of the Autochtonous. Source rocks are the same as above. All classical Autochtonous reservoirs are viable in this play. Seal is provided by the evaporitic detachment itself.

From these three possibilities, we prefer the third solution. The wide-spread indication of evaporites, combined with the distant surface exposures suggests the existence of a more developed, areally widespread sheet of evaporites. The limited size of intrusions (Hawasina Window) and the stratiform nature (Qumayrah half-window) suggest a relatively thin body. These points to a detachment, which could explain the mobility of the nappes, as well as geometrical requirements of the Sumeini structures.

Conclusion

Structural dips and magnetotelluric data suggest a major dome beneath the Hawasina Window. This dome would correspond to the upwarp of the Autochtonous, similar to Jebel Akhdar. The axis of the dome strikes NW-SE. In the southern zone of this dome we observed several occurrences of small gypsum diapirs which rise from beneath the Hawasina Nappes. We suggest that they originate from the Late Precambrian or the Permian of the underlying Arabian Platform, indicating the presence of the Autochtonous series below the Hawasina Nappes. Due to another possible model they can originate form the basal detachment of the Sumeini Units.

In all three cases the existence of the evaporite point to the presence of the Autochtonous series below the Hawasina culmination and shows the possibility to explore the classical hydrocarbon systems of the Arabian Peninsula below the rugged terrain of the Oman Mountains.

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