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An Overview Of The Evolution And The Petroleum Systems Of The Eastern Ghadames (Hamra) Basin - Libya

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Introduction

The Hamra basin constitutes the eastern portion of the vast Ghadames Basin, an intracratonic Paleozoic sag located on the North African Platform.

The intensive exploration conducted in the basin by Agip and other oil companies since the 1950's has led to several hydrocarbon discoveries and to a deep geological knowledge of the area. This paper presents an overview of the area in terms of structural history, petroleum system and some peculiar aspects which affect the occurrence and productivity of the hydrocarbons.

Geological setting and basin history

The Hamra Basin is bounded by two major tectonic elements, the Dahar-Nefusa Uplift to the north, and the Qarqaf Uplift to the south (Fig. 1). The eastern limit of the basin is less defined due to the interference with the Hon Graben and the Waddan Uplift, which represent the western margin of the Sirte Basin's structural domain.

The today's setting of the basin reflects the general evolution of the whole North African Platform. The latter can be subdivided into three main tectonic phases: 1) a Paleozoic generalized subsidence, 2) an uplift with widespread erosional phenomena during the Hercynian Phase and 3) a regional extension with overall tilting towards north-west during the Mesozoic.

In the Hamra Basin the Paleozoic subsidence created most of its basin fill. Deposition started with the Cambrian to Lower Ordovician succession, a sequence of continental to shallow marine sands (Hassauna and Haouaz Formations), and was followed by the deposition of a package of transgressive marine shales (Melez Chograne Fm). During the Late Ordovician the area was covered by a thick ice sheet: this event was a consequence of the southern - near the South Pole - geographical position of the North African Platform during that time. At the beginning of the Ashgillian stage, an uplift of the area occurred and the subsequent erosional activity by the ice cover determined the creation of a series of large and long troughs, which were later filled by fluvio-glacial and glacio-marine deposits: the Memouniat Formation, one of the area's hydrocarbon reservoirs, is an interesting example of sequence deposited under these environment conditions. The formation consists of sandy periglacial deposits in the southern part of the basin, near the Garghaf Uplift, and by more shaly glacio-marine deposits in the north. Because of the glacial origin, rapid vertical and lateral facies variations are quite common in this formation: the distribution of sand bodies is irregular and directly related to the paleo-topography generated by the erosive actions of the ice sheet.

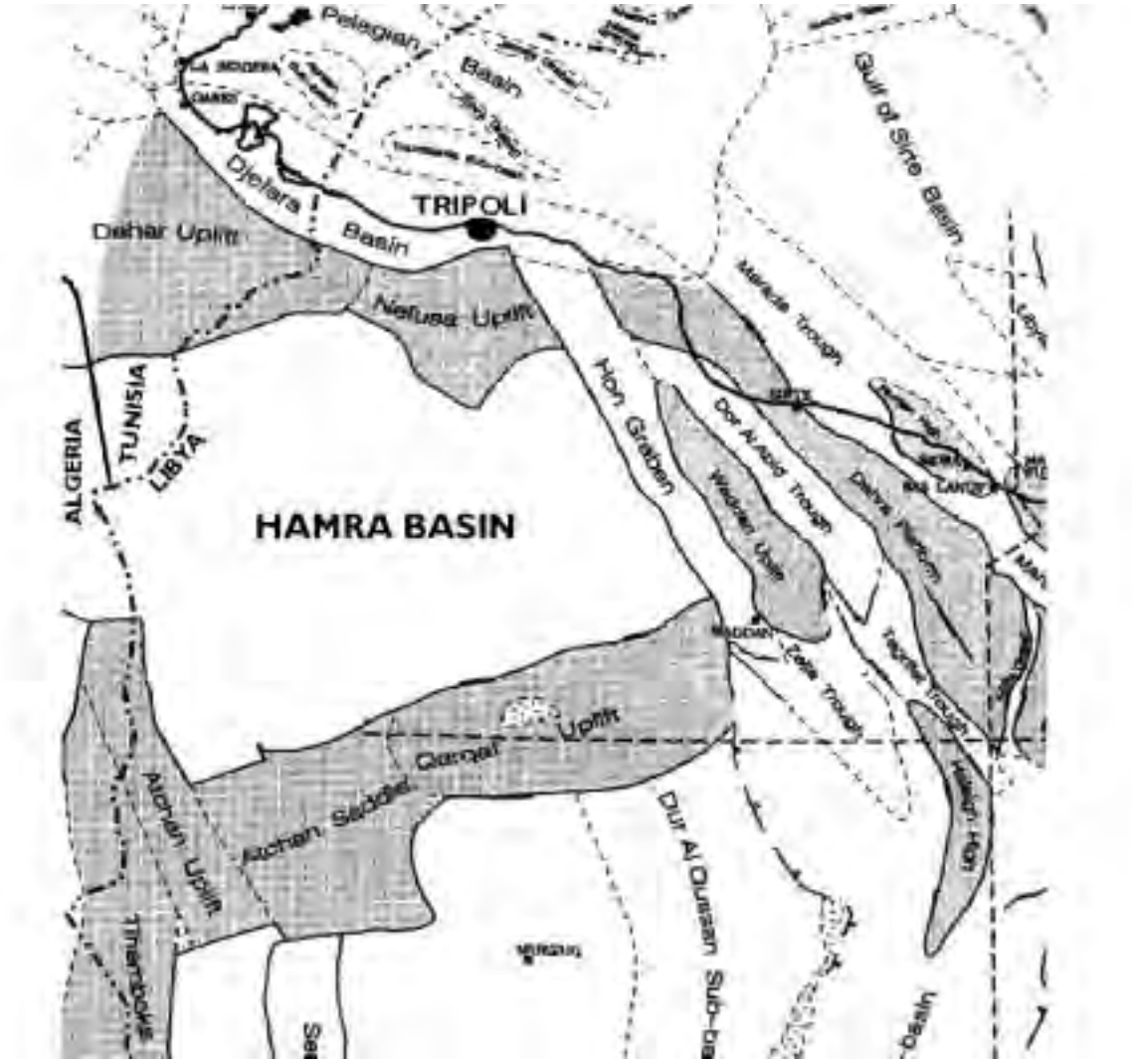

Fig. 1. Regional framework of the studied area.

The Taconian unconformity marks the transition to the Early Silurian sequences. An extensive marine transgression (Llandoverian stage) occurred leading to the deposition of the Tanezuft Formation, a shaly interval with at the base a highly radioactive and organic rich level ('Hot Shales').

On top of these shales, a sandy interval, the Acacus Fm., deposited in a prograding deltaic environment: its basal members are known to constitute the most important reservoirs of the Hamra Basin.

Another important tectonic event occurred at the base of the Devonian time. This event is referred to the Caledonian orogeny and determined the uplift of the southeastern area and the erosion of part of the Acacus Fm. Above the new unconformity, the fluvio-deltaic and shallow marine sands of the Tadrart Formation deposited. The subsequent Devonian succession includes the transgressive shallow marine sands of the Ouan Kasa Fm, the Emgyat Shale (maximum flooding event), the Aouinet-Ouenine Fm. (shelf sands overlain by shallow marine shales – the latter including some organic rich shale layers in the upper section) and the sandy Tahara Fm, of shelf environment.

During the Carboniferous several mostly shaly units of shelf and shallow marine environment sedimented in the basin (e.g. M'rar, Assedjefar, Tiguentourine formations). This

sedimentation was then abruptly interrupted by one of the major events which affected the entire structural setting of the Ghadames Basin and Hamra Basin: the Hercynian Phase. This phase (Westfalian to Early Permian in age) determined the uplift of the Dahar-Nefusa Arch and several other movements, as well as a strong but uneven erosion of the area. A regional tilting caused also the depocenter of the basin to shift towards the north.

The Mesozoic sedimentation was characterized by clastics, carbonates and evaporites sequences with an overall wedging towards the north. The fluvio-deltaic sandstones of the Lower Triassic (Ouled Cheb and Ras Hamia formations) are reservoir of some importance.

During Tertiary the tectonism of the North African Platform was related to the Alpine orogeny: the effects mainly derived from the re-activation and inversion of the Hercynian faults and were rather weak. No significant sedimentation occurred in the basin during this era.

Petroleum system

The primary petroleum system of the Hamra Basin has been located in correspondence of the Late Ordovician to Middle Devonian section. The source rock is the Silurian Tanezzuft Formation, which has a wide distribution and thickness (up to more than 400 m) and can attain 17 % of TOC at the high radioactive basal Hot Shales level. This source is prolific and well known in many other regions of the North Africa as well.

The overlying, still Silurian, Lower Acacus deltaic sands represent the most important reservoir of the area with porosities ranging 10-20% and permeabilities being often higher than 100 mD. The Late Ordovician Memouniat Fm, which lies below the Tanezuff Fm, is another target reservoir, with porosities ranging 8 to 12%, and fair permeabilities. Other less important reservoirs are in the Lower and Middle Devonian (Tadrart, Ouan Kasa and lower members of the Aouinet-Ouenine Fm.)

The principal traps of this system are structural and consist of small-size anticlines, Hercinian in age. These structures are rather limited in vertical closure, which implies that a relatively small amount of hydrocarbon reserves is usually found. In the northwestern part of the basin, several discoveries of this type have been made at the Lower Acacus reservoir (concessions NC100, NC118, NC02 and NC01), while in the southeastern area they occurred mostly at the Memouniat Fm. level (concessions 66, NC40 and NC02). The El Hamra Fields are among the oldest and most important fields of the basin: they give evidence of another and less common type of structural trap, the oil having been encoutered in updip closures of the Tadrart Fm against faults, and in several adjacent faulted blocks.

Stratigraphic traps may be found as pinch-outs (e.g. in El Wafa Field, where hydrocarbons are trapped in a large termination of the Aouinet-Ouenine sands against the Tiemboka High) or as toplaps against unconformities (e.g. Acacus sands against the Hercinian unconformity in the Tigi Field).

The upper shale levels of Aouinet-Ouenine Fm. (Devonian) represent the source rock of another shallower and less important petroleum system. These shales are generally characterized by a relatively reduced thickness and a TOC ranging 3-5%. Hydrocarbons expelled from this source are sometimes encountered in the Tahara Fm. (Devonian) and in the lower Triassic sandstones of the Ouled Cheb and Ras Hamia formations. In addition to the usual anticlines, some stratigraphic traps are also found (e.g. onlap of the Triassic sandstones on the Hercinian unconformity). The potential of this system is still poorly tested.

In terms of hydrocarbon migration, the overall limited tectonic activity occurred in the basin has in general significantly reduced the possibility of vertical escape through fault systems: therefore, migration occurred preferably through the reservoirs which were directly overlying or

underlying the source rock. Moreover, lateral migration distances are supposed to have been rather limited.

Another factor affecting the occurrence and distribution of the hydrocarbons in the basin is the hydrodynamic regime. The Upper Silurian - Lower Devonian aquifer complex is marked by a neat increasing trend of formation water salinity and hydraulic pressure from south-west towards the central part of the basin. This is due to the action of the meteoric waters which have entered these formations from the outcrops of the southern basin margin during a long span of time. This phenomenon may have affected the migration as well as the re-migration of some hydrocarbon pools. Moreover, the intra-formational fluid motion being still ongoing, the hydrocarbon-water contact of some fields may appear slightly tilted.

Finally, some diagenetic phenomena have an important role on the petrophysical reservoir characterization. The presence of chlorite cement, lining the pore space (fig. 2), determines the deterioration of porosity and permeability. This is also coupled with a general decrease of formation resistivity even in case of hydrocarbon bearing levels with very low water saturation, which can make it difficult to evaluate from log analysis the actual potential of an hydrocarbon pool.

Acknowledgments

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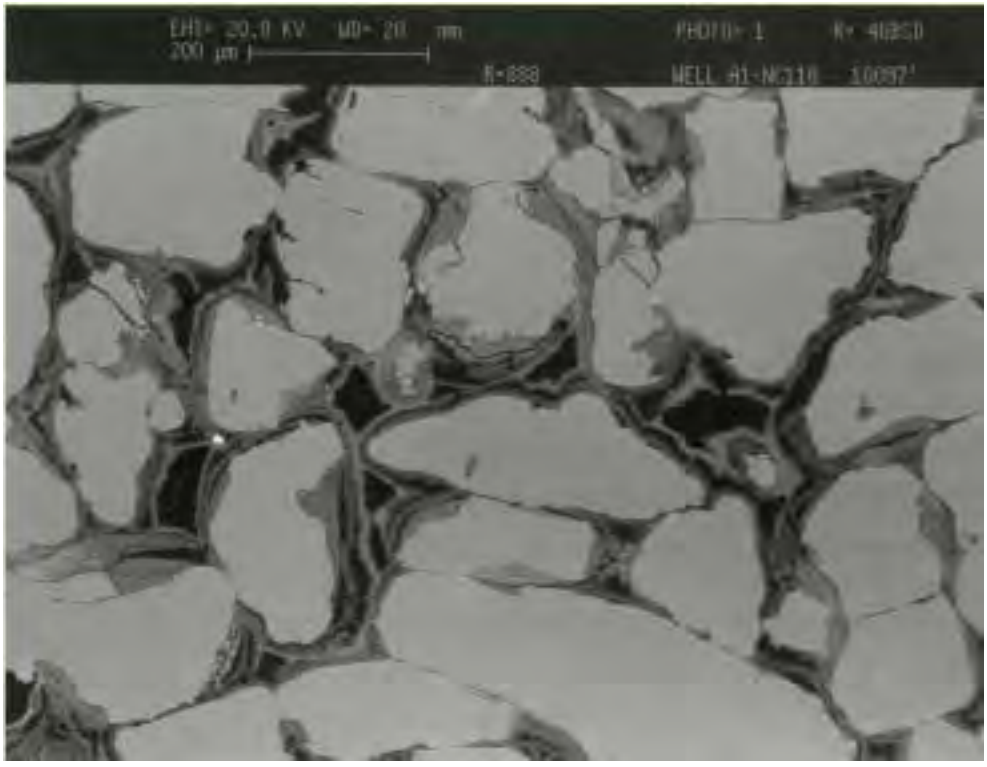

Fig 2. Pore lining: Fe-Chlorite coatings on pore throats affects porosity and permeability.