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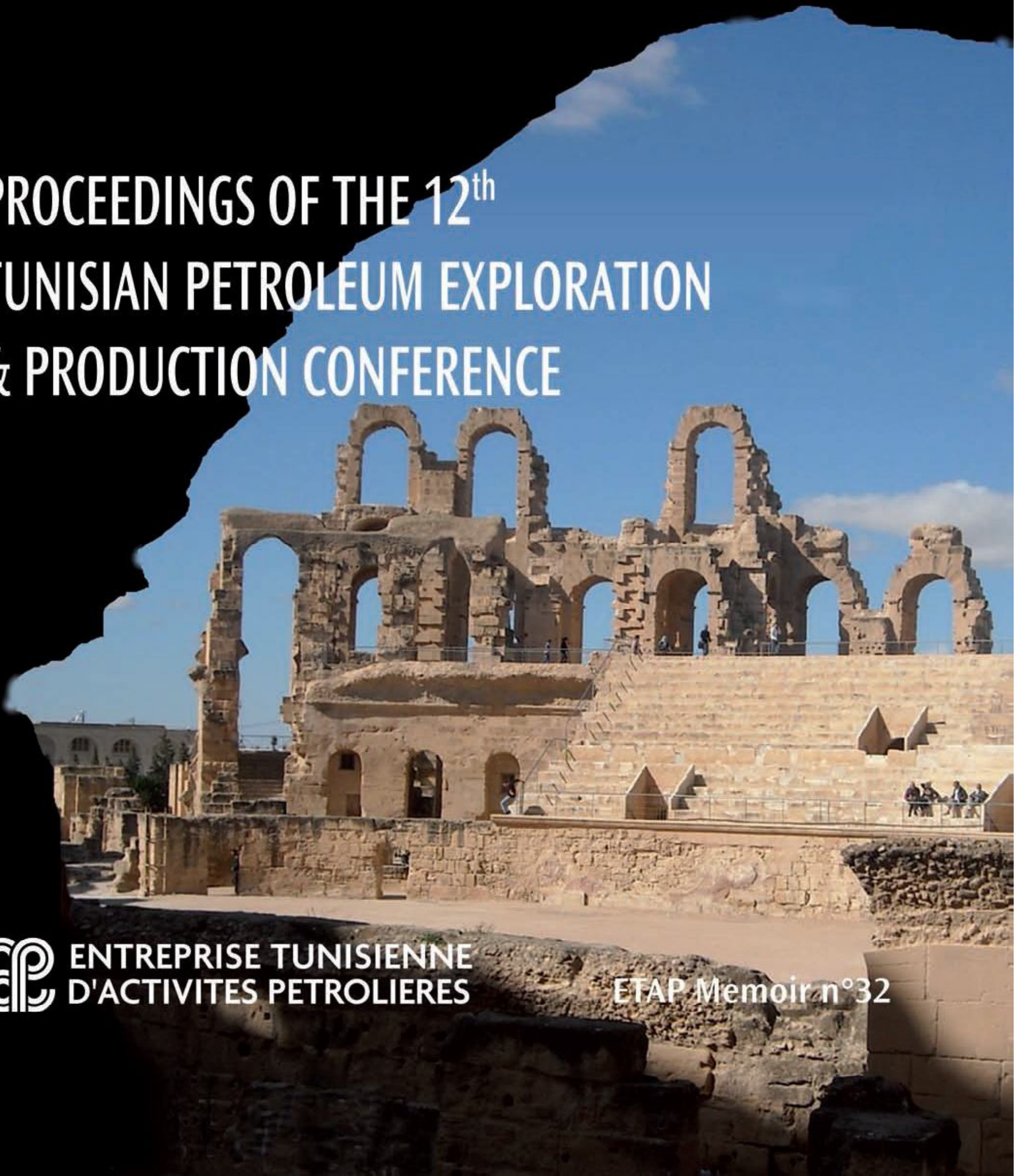

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THE GEODYNAMIC EFFECTS ON DIAGENESIS AND RESERVOIR ASPECTS OF EARLY EOCENE PELAGIC CARBONATES IN NORTH-WESTERN TUNISIA

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ABSTRACT

As commonly known, the Bou Dabbous Formation constitutes a proven source rock in certain hydrocarbon fields in Tunisia and also a proven fractured reservoir as at Belli and El Manzah fields (Cap Bon area); this study is focusing on the reservoir potential of the equivalent of the Bou Dabbous pelagic limestones, located in the northern Tunisia thrust belt zone.

In the north-west of Tunisia, diagenetic modifications, especially dolomitisation, burial leaching, cementation, etc., which occur in a particular geodynamic context, mainly characterised by a subsidence activity and tectonic movements including thrusting; appear improving the reservoir quality of the pelagic carbonates. The latter could be considered as an additional regional target in the studied area and also in nearby sectors such as the northern offshore of Tunisia.

Petrographical analyses show that Early Eocene pelagic carbonates exhibit varied porosity types. Despite the frequency of stratiform stylolites suggesting compaction processes and thus an obvious burial signature, vuggy and intercrystal pores, are at least locally, common. Each pore type appears controlled by the initial sediment texture.

It appears that the thick overburden related to thrust sheets and significant subsidence could be the main process providing a particular diagenetic signature leading to enhance the reservoir properties of initially "tight" pelagic limestones.

1. INTRODUCTION

Subthrust plays have been tested in several orogenic belts of the world. Therefore in northern Tunisia, new significant hydrocarbon reserves may occur in subthrust autochtonous and parautochtonous series buried below the frontal zones of the thin-skinned thrust belts.

The complex structural and morphologic features, if combined with source rocks, reservoirs and proper burial history, represent potential hydrocarbon play.

The emplacement of the wedge-shaped thrust belts, providing a regional seal, greatly enhances the hydrocarbon generation from sources within the subthrust plate and can also increase the porosity of some tight reservoirs such as the Early Eocene pelagic limestones by burial corrosion and dolomitisation processes.

Subthrust plate, corresponding to the autochtonous and parautochtonous zones, is formed by Late Cretaceous to Eocene series. Burried below the frontal zone of the Numidian thrust belt, this subthrust plate represents a good play system in the region (fig.1&2).

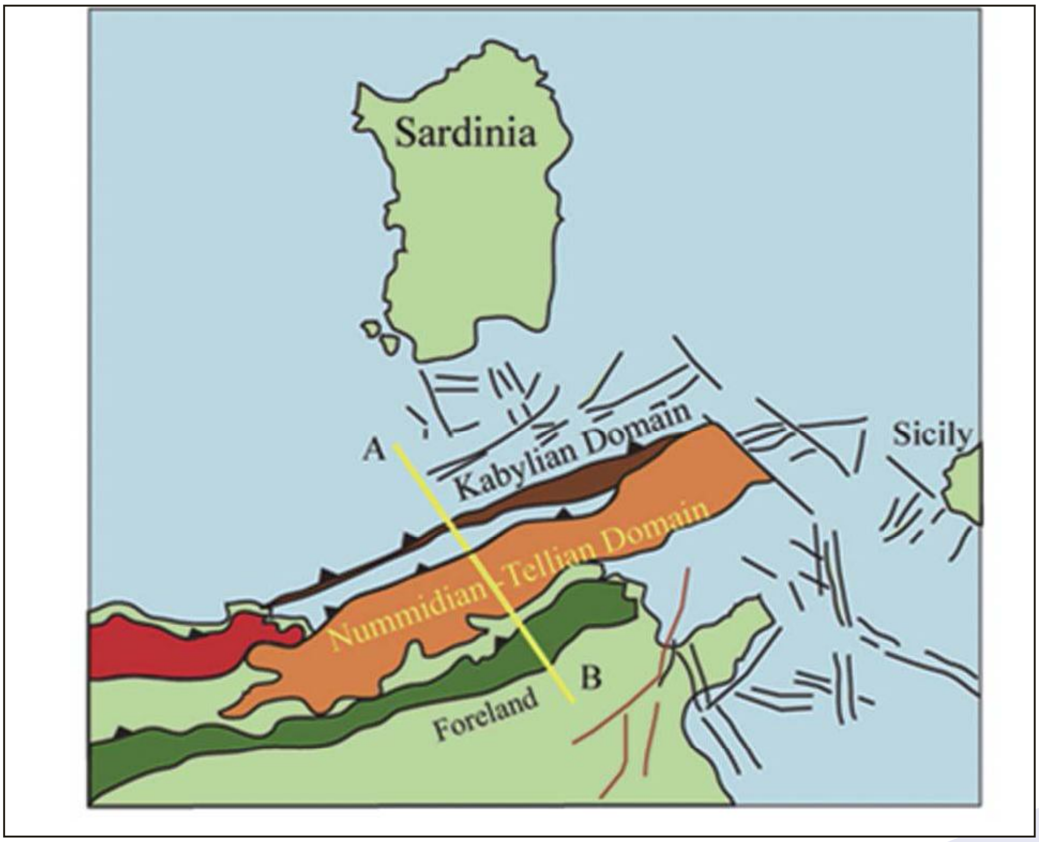

Fig.1. Major structural elements of northern Tunisia (Fourati et al., 1998)

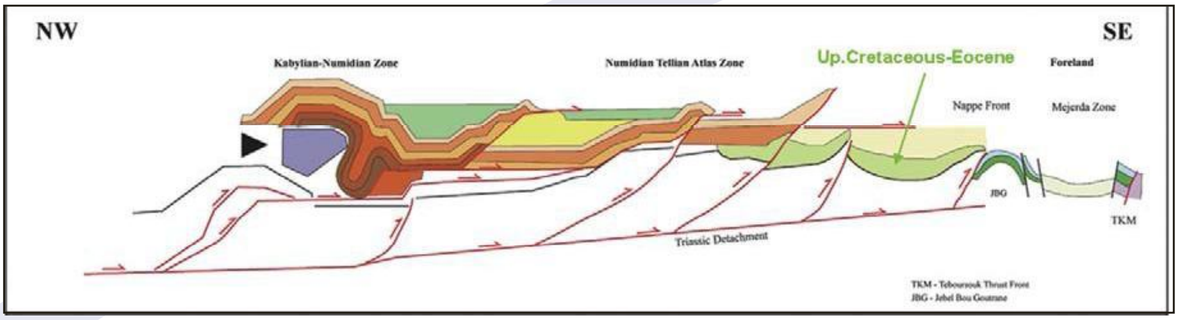

Fig.2. Cartoon of the structural zones, offshore/onshore northern Tunisia (Fourati et al., 1998)

Geographically, the studied area is located in north-western Tunisia, in area extending from the "Numidian zone" to the "Imbricated zone", between Nefza and Kasseb villages (Rouvier, 1994; fig.3).

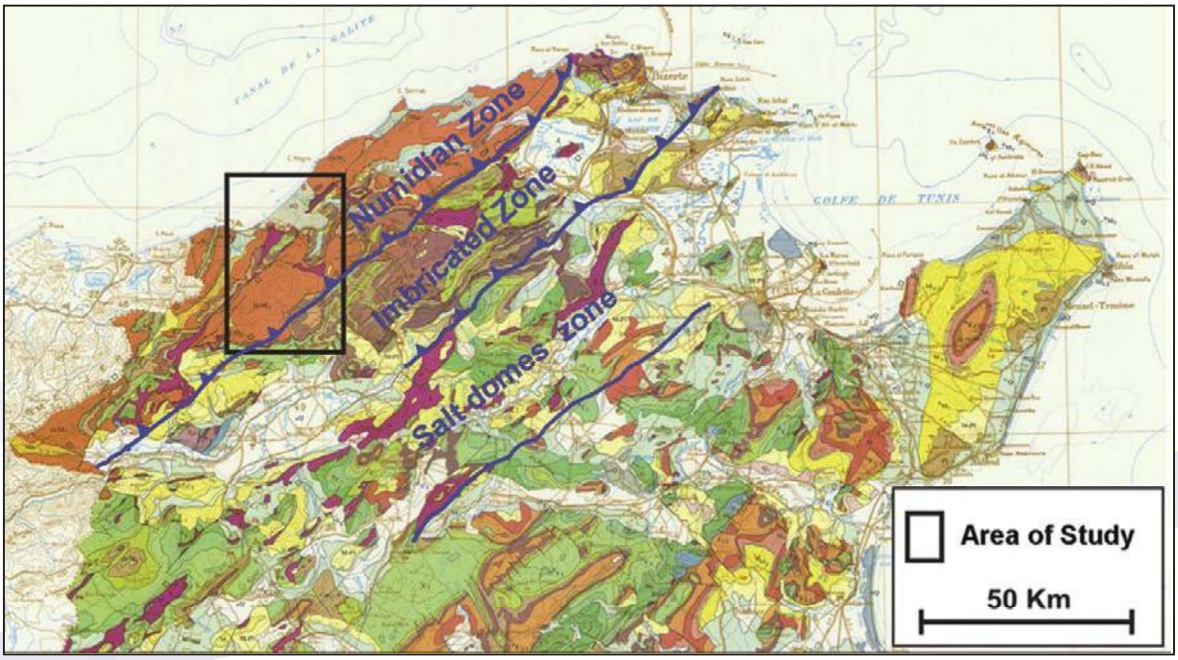

Fig.3. Studied area location on the Geological map of Tunisia. Eocene exposures are marked withbrown colour.

The lithostratigraphic column of northern Tunisia shows the occurrence of a detachment levels set in the sedimentary pile. The series start from the Triassic evaporates to the Quaternary deposits (Fourati et al., 1998; fig.4).

The main reservoirs are the Triassic and Late Jurassic carbonates, the M'cherga sandstones, the Abiod and Ypresian limestones and the Oligo-Miocene sandstones. The seals of these reservoirs are all the overlying shaly levels.

The principle and most known source rocks are the M'cherga claystones, the Bahloul and the Bou Dabbous argillaceous limestones and the Numidian shales (Fourati et al., 1998).

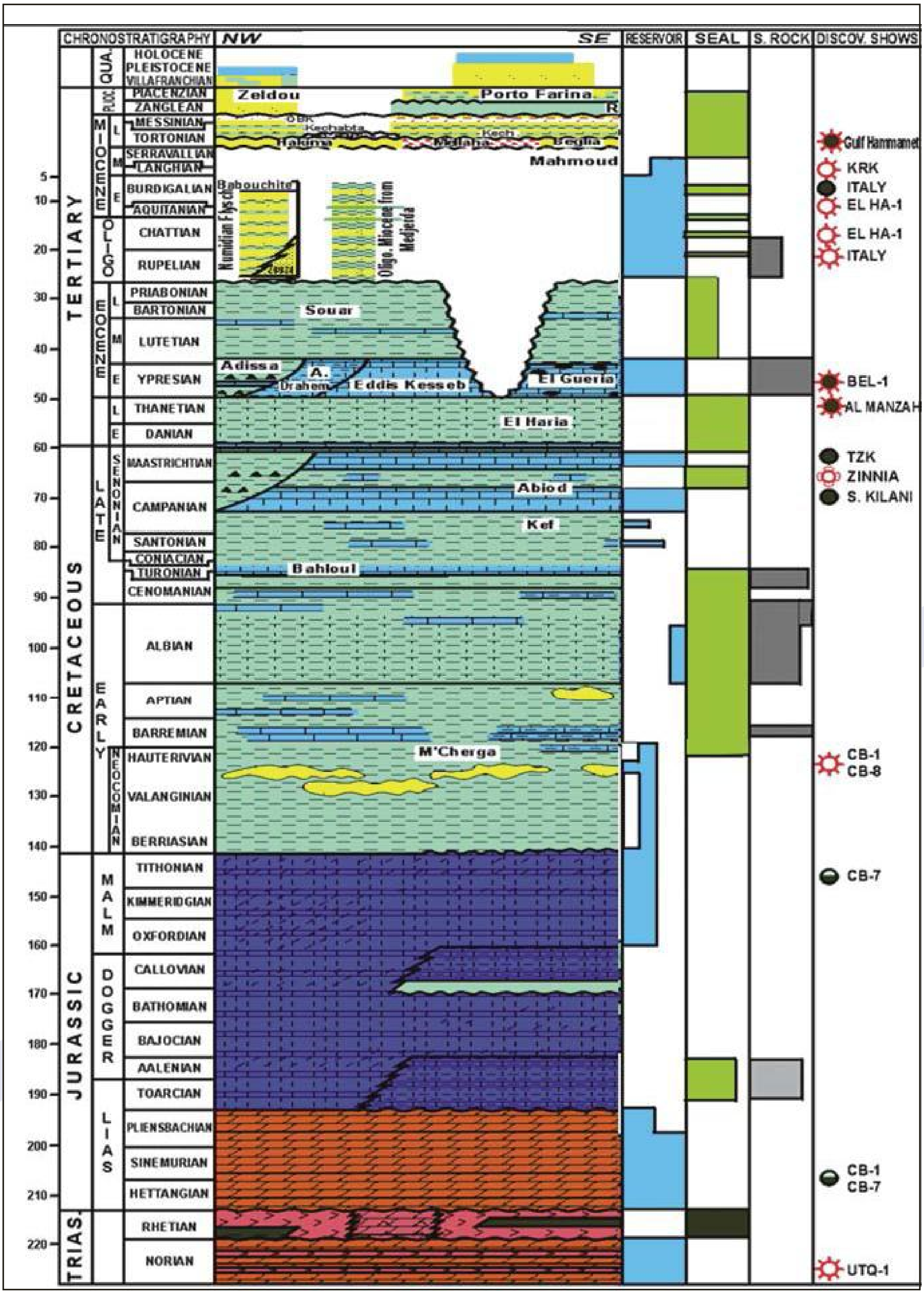

Fig.4. Lithostratigraphic chart (modified from Fourati et al., 1998)

2. GEODYNAMIC CONTEXT

The interpretation of the two available seismic sections (fig.5&6) in the studied area, has shown three important points: the presence of some reverted normal and listric faults, the importance of salt and shale detachment levels for the thrusting movement, and the influence of salt to have different vergences and variable thicknesses.

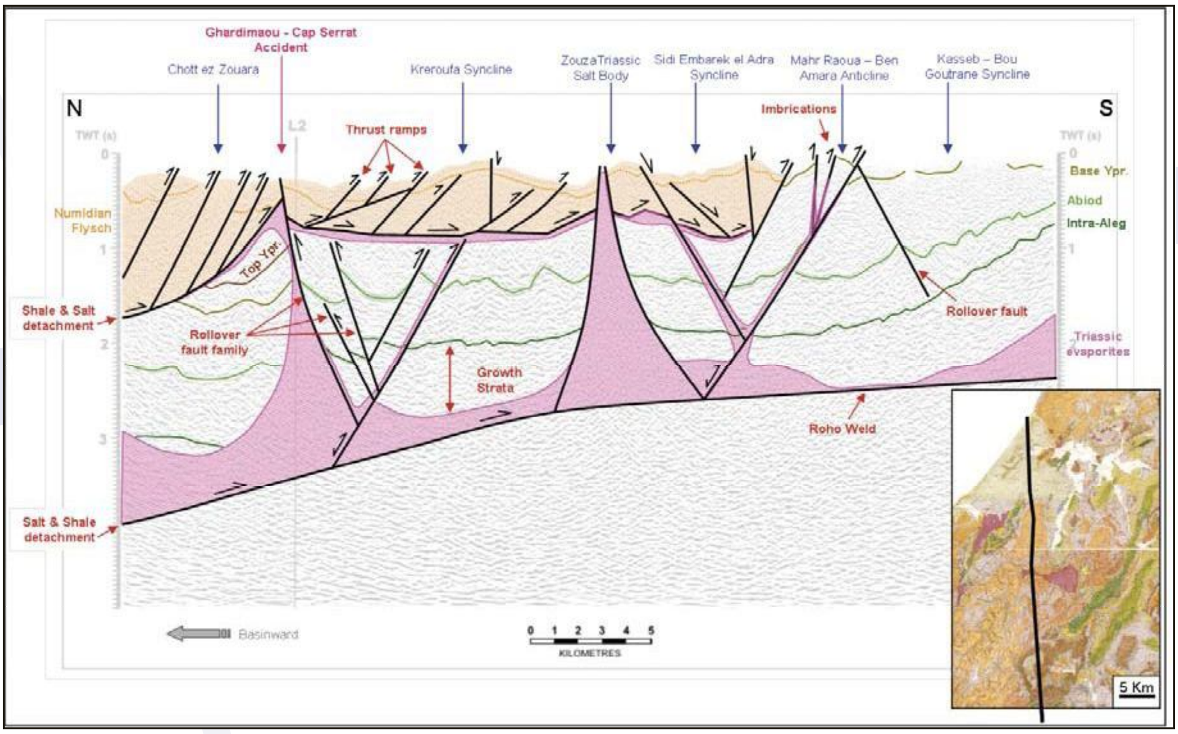

Fig.5. North-South seismic cross-section

Among the models considering the structures and the geometry in a thrust belts context, we retain two main types of thrust belts (Shaw et al., 1992):

- Thin-skinned thrust belts, soling to basal detachments with low hanging-wall angle and same stratigraphic levels of the thrust sheets.
- Thick-skinned thrust belts, extending to depth and do not sole to basal detachments with high hanging-wall angle and high stratigraphic levels towards the hinterland.

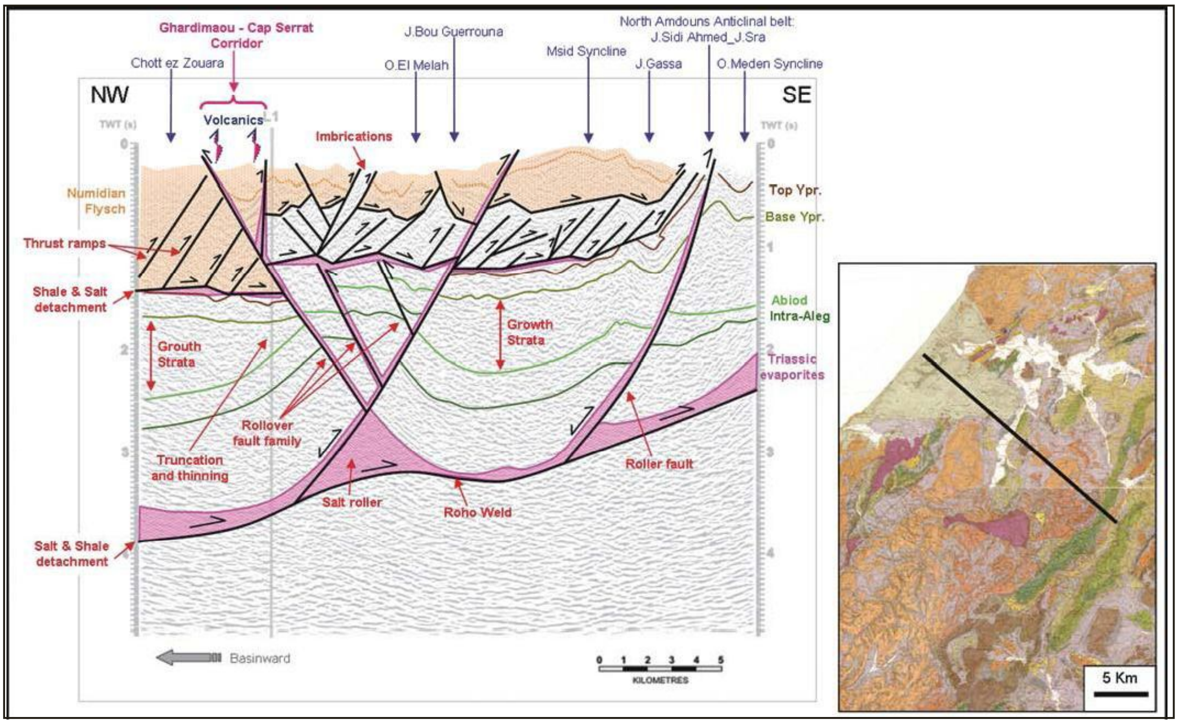

Fig.6. NW-SE seismic cross-cection

These two models may be applicable in our studied area. In that case, the thin-skinned thrust belts correspond to the “allochtonous” and “parautochtonous” units while the thick-skinned thrust belts correspond to the “autochtonous” units.

The seismic sections revealed also two styles of thrusting tectonic, as defined by Jackson and Talbot (1991), thrust belts:

- With salt decollment generating broad fold and thrust belt with no consistent vergence

- Without salt decollment generating narrow fold and thrust belt with consistent vergence

Concerning the tectonic evolution, responsible of the currently seen structures, the main orogenic phases are: the Pyrenean compression and the Alpine compression.

Many events, tectonic and/or eustatic in origin, are identifiable in the Late Cenozoic chart (Fourati et al., 1998) such as the lower Oligocene, Tortonian and base Pliocene unconformities, base Miocene and the Pliocene transgressions, the Serravalian thrusting and the Tortonian-Messinian thrusting and folding (Ben Ayed, 1993; Fourati et al., 1998; fig.7).

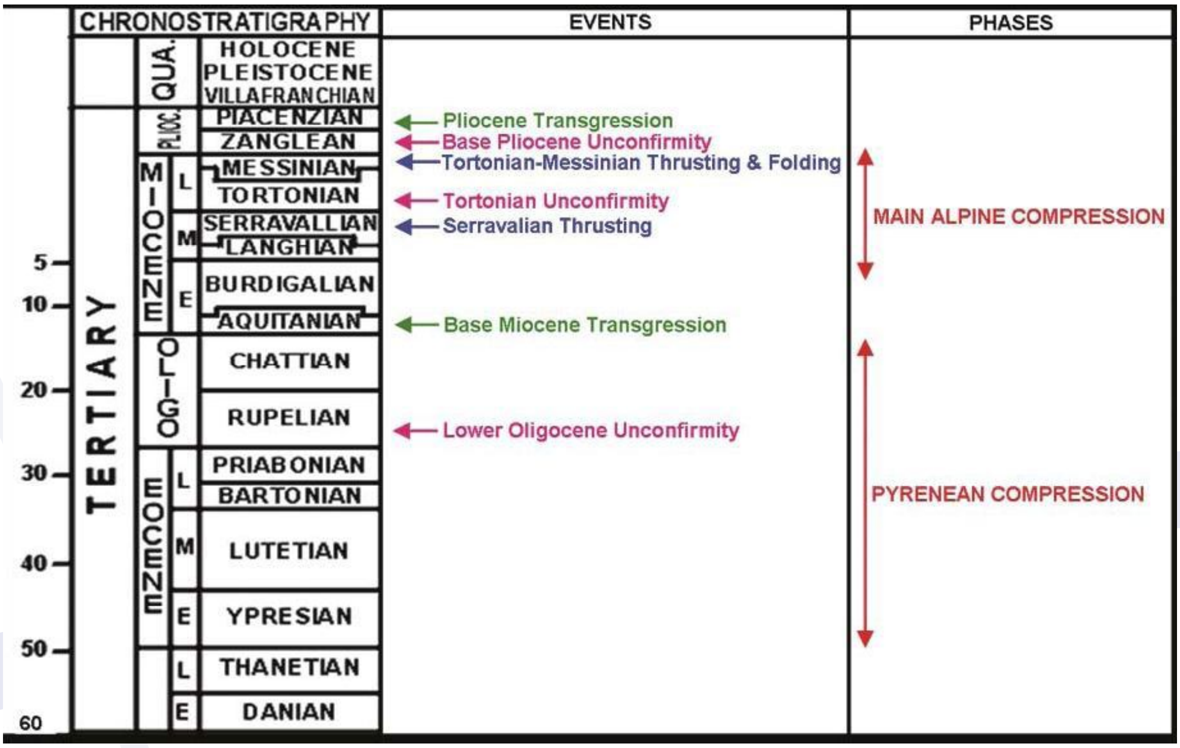

Fig.7. Tertiary events chart (after Fourati et al., 1998)

The pre-deposition morphology of the Ypresian series in northern Tunisia was dominated by tilted block structures: horsts, grabens and half-grabens (Ould Bagga et al., 2006). It was probably formed from the West to the East, by the known Hairech Paleohigh, the tilted blocks of Beja, Ain el Bey-Bou Gotrane, Eddiss and Ain Draham half grabens, Nefza horst and Kasseb graben; and the Salt diapir which still acting in Ain el Bey locality (Rouvier, 1977, 1994; fig.8).

The geodynamic evolution of the Ypresian sedimentary series starts since the Pyrenean phase with the reactivation and the inversion of the listric normal faults. The Numidian flysch deposits took place as a result of the decollement and the thrusting of the Mediterranean metamorphic nappes. Then, the decollement and a mobilization of the numidian nappes come after with the Serravalian phase; As a final stage, come up the thrusting and folding of all the sedimentary units.

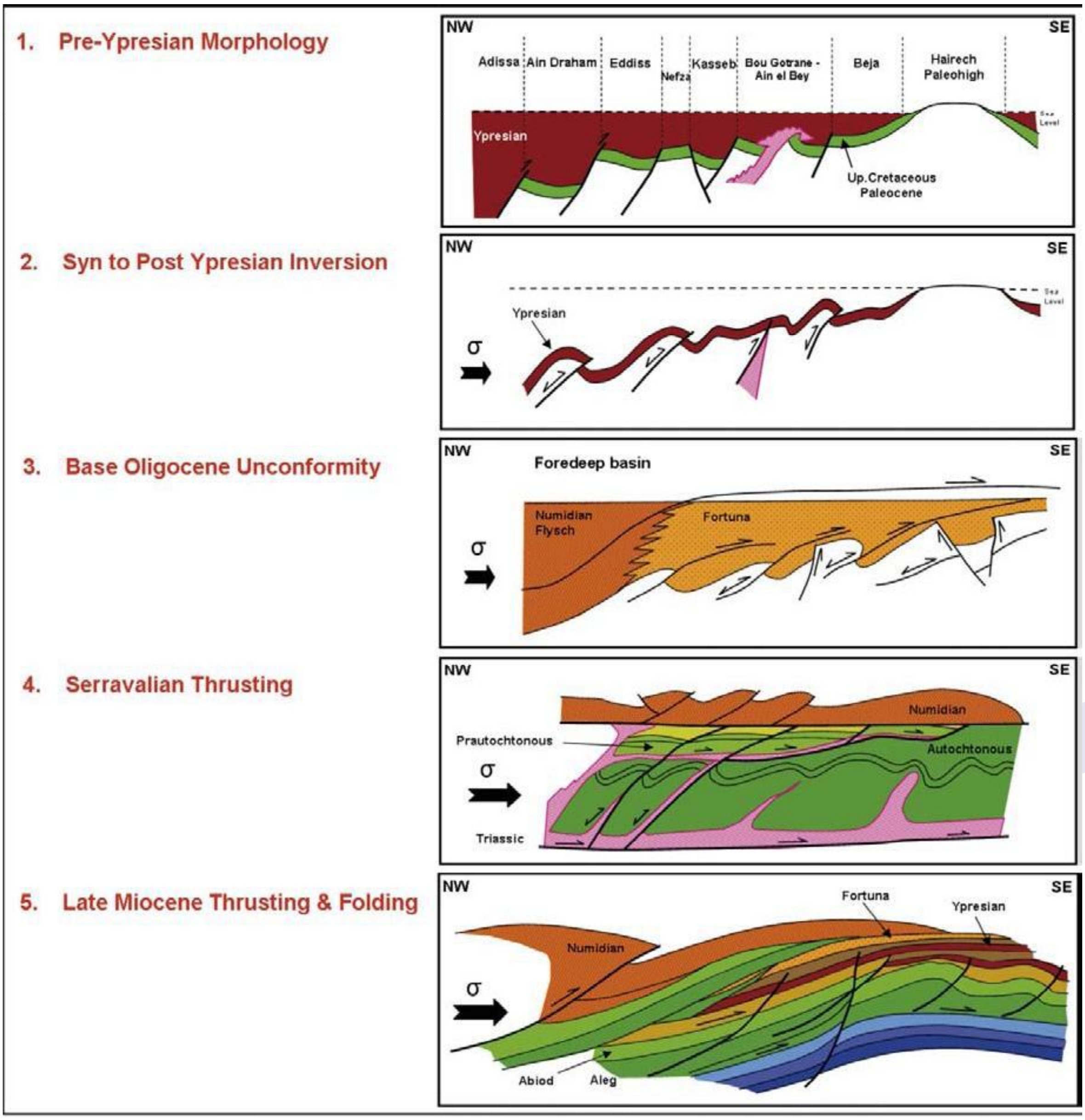

Fig.8. Geodynamic evolution and deformation model of the sedimentary series in northern Tunisia

3. SEDIMENTOLOGIC ANALYSIS OF THE BOU NAZERINE SECTION

3.1.The facies succession

The Oued Bou Nazerine outcrop is located South of Ain Allega area (fig.9). An important fault discontinuity separates the Eocene limestones from the Triassic evaporates (Rouvier 1977, 1994).

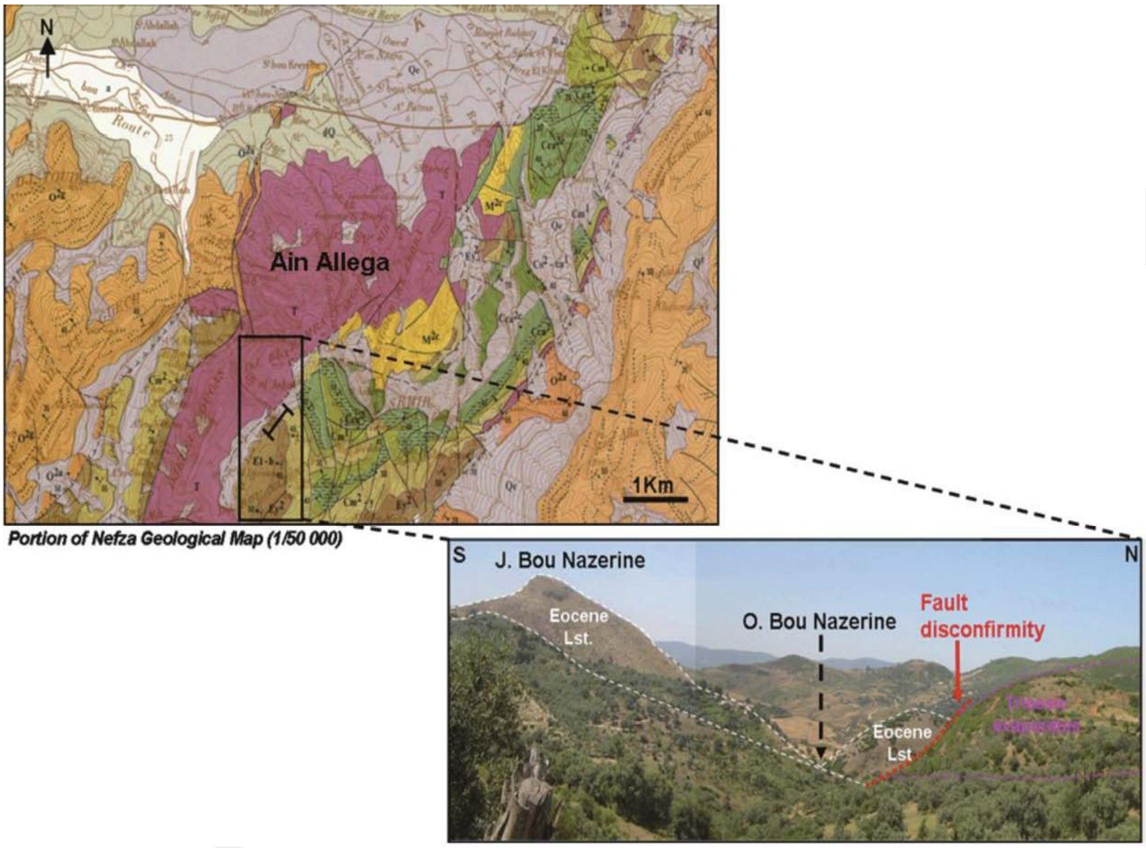

Fig.9. Oued Bou Nazerine outcrop location (Nefza region)

From base to top, the Bou Dabbous formation in the Bou Nazerine section could be subdivided into two main ensembles (fig.10).

The lower ensemble (40m in thickness), is characterised by the frequency of cherty limestone beds within the thinly bedded to laminated limestones. Some sedimentary structures such as hummocky cross beddings (HCS) and bioturbation structures are identified. In addition, particular deposits such as breccia lensoid layers are occasionally present. The representative facies of this ensemble consist to mudstone-wackestone rich in radiolarians associated to planktonic foraminera. The accessory components are floating sponge spines and scarce phosphatic grains.

The upper ensemble (80m) is formed of thicker and more massive limy beds. The main facies are packstones rich in planktonic microfauna mainly corresponding to globigerinids which are associated to globorotalids and very scarce radiolarians.

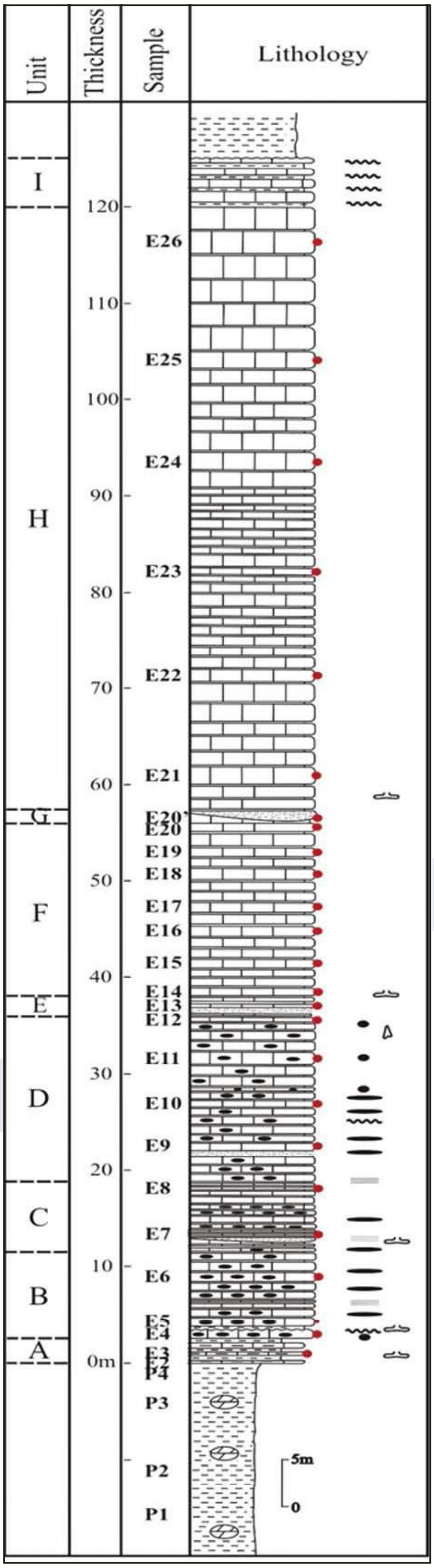

Fig.10. Lithological and sedimentological description of the Bou Nazerine outcrop

3.2. Diagenetic Features

The lower carbonate ensemble is mainly marked by dolomitisation and silicification processes whereas the upper part rather exhibits compaction features (Friedman, 1964; Bathurst, 1975; Purser, 1980; fig.11).

In contrast, solution features appear generalised to the whole section. They affect bioclasts (fig.12-C), matrix or even the dolomite rhombs newly formed. Solution is not due to sub-areal exposure dissolution (Lohmann, 1988), it appears occurring in burial conditions.

As mentioned in our section, dolomitisation is commonly associated to biosiliceous sediments (Beavington-Penny et al., 2008). It can be earlier (Dapples, 1979), concomitant (Jacka, 1974) or later than silicification (Bernoulli and Gunzenhauser, 2001).

In our studied section, dolomitisation is preferentially pore-filling inside the allochem lodges “intra-particle dolomitisation” (fig.12-A) and as disseminated rhombs in the muddy sediment “dolomitisation of micrite matrix” (Loucks et al., 1998; Macauley et al., 2001). In the micrite matrix, dolomite crystals are not detrital but indicate in situ growth during diagenesis of a predominantly biosiliceous sediment as displayed by their well-developed crystal faces (fig.12-B; S.J Beavington-Penny et al., 2008).

The cementation is also an important feature affecting the Bou Dabbous limestones. It occurs mainly within the fractures (fig.12-D).

Silicification process appears related to the remobilization of biogenic silica contained within microfauna such as diatom and radiolarian oozes (Henchiri, 2007). In fact, the micrite limestone of the lower ensemble contains frequent radiolarians and some sponge spines. Diagenetically altered the radiolarians release biogenic silica material which precipitates as cherty concretions or as entire layers. Consequently, silicification processes are interpreted as syn-sedimentary features.

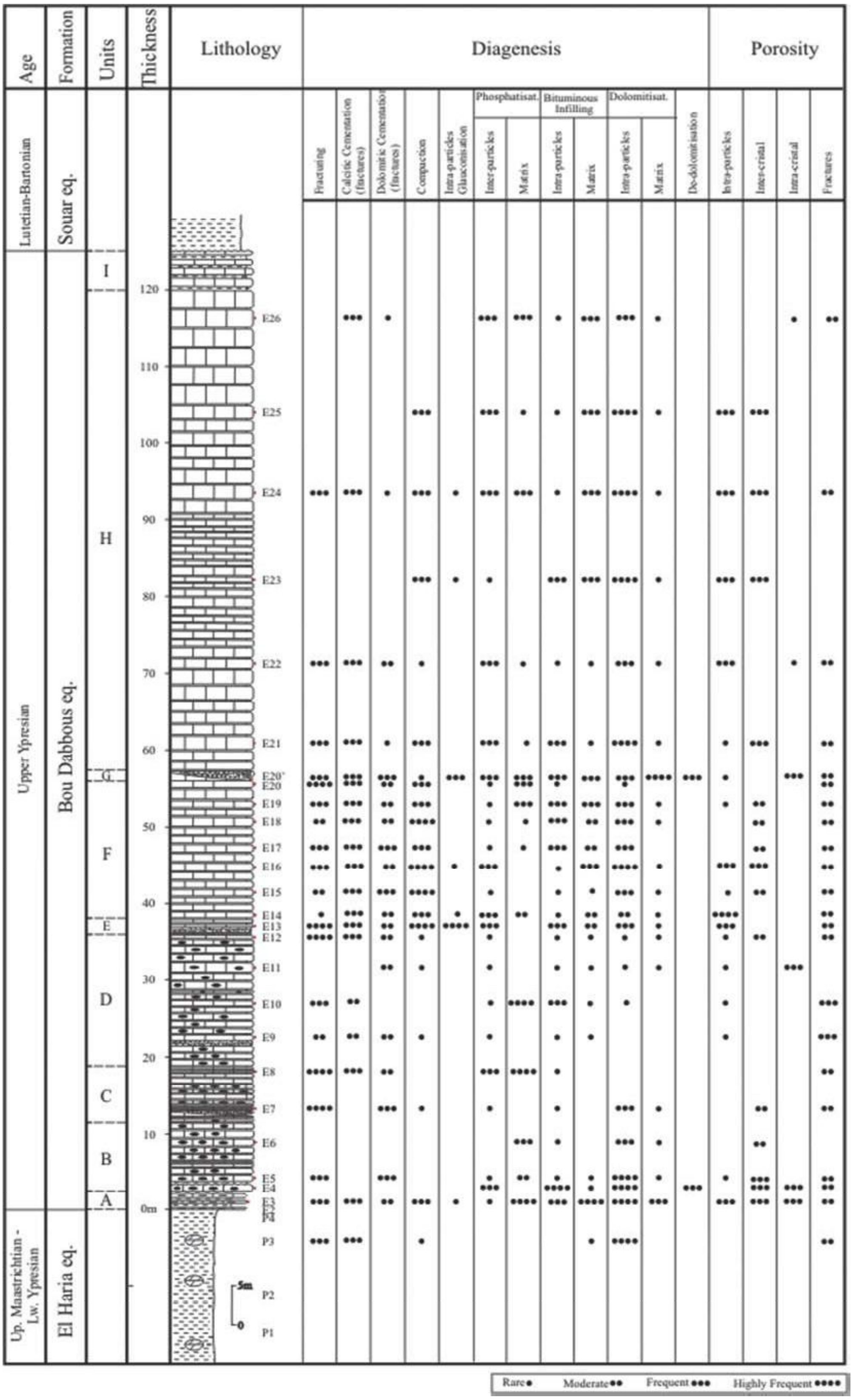

Fig.11. Digenetic processes and pore types and frequency within the Early Eocene carbonates

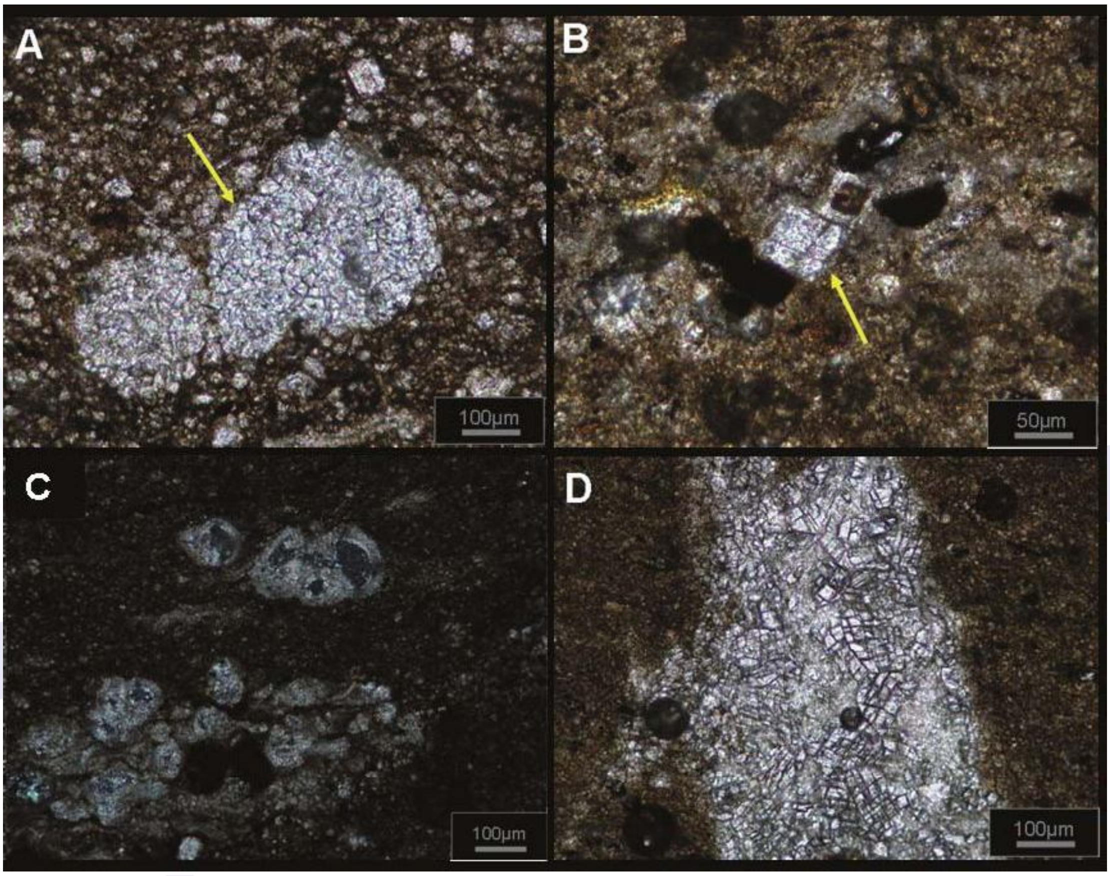

Fig.12. Photomicrographs of the digenetic processes within the Early Eocene carbonates. A-Intra-granular dolomitisation; B- Matrix dolomitisation; C-Dissolution creating intraparticle pores; D-Dolomitic cementation in fractures

In the upper ensemble, compaction processes, which are predominant, are mainly expressed by stratiform stylolites and frequent truncated foraminifera (fig.13).

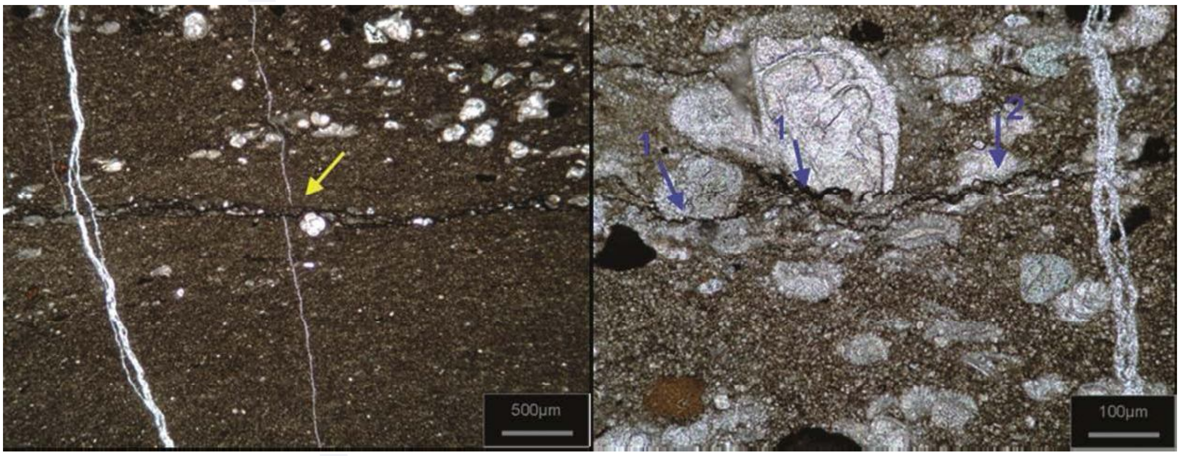

Fig.13. Compaction features. A- Post-dating stylolite B-Foraminifera truncated (Labelled 1), Dissolution preferentially developped in stylolites (Labelled 2)

4. BURIAL DIAGENESIS AND RESERVOIR ENHANCEMENT AS A RESULT OF A PARTICULAR GEODYNAMIC CONTEXT

In addition to compaction features which are preferentially visible in the upper ensemble, frequent solution fabrics, occur within the micritic matrix. Solution cavities are preferentially identified along the stratiform stylolites. It means, in terms of diagenesis chronology, that solution processes are post-dating stylolites occurrence and thus compaction features. Solution processes generate new moldic and vuggy pores which are added to the more common but largely ineffective intra-particle porosity within foraminifer tests.

Considering the reservoir quality, this uncommon burial solution is linked to the overburden impact which enhances largely the porosity likewise the permeability. The creation of vuggy pores contributes to the reservoir potential enhancement of the Early Eocene Bou Dabbous pelagic limestones presumed to be "tight".

Late burial cements may locally occlude the vuggy pores but the most pertinent phenomena is their infilling by bituminous material (Romano et al., 1981; fig.14), probably created during burial diagenesis.

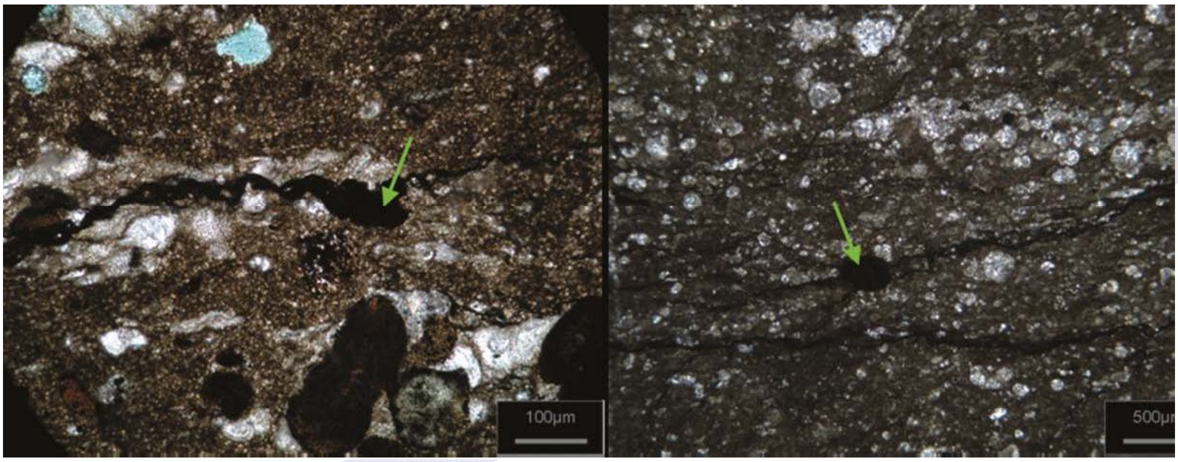

Fig.14. Bituminous material infilling vuggy pores

These results could be compared to those obtained in other settings. Burial solution features were also identified within El Garia reservoir in the offshore Tunisia (Ashtart, Didon, Hasdrubal and Zarat fields). They were interpreted as linked to aggressive fluids likely magnetic CO2 sourced from Cretaceous volcanics, flowed into the reservoir during burial diagenesis via faults above the salt dome and were driven by elevated heat flow above the salt (Magara 1978, Beavington-Penny et al., 2008); comparable conditions may characterize the studied outcrop in the vicinity of the outcropping Ain Allega diapir. In addition, this area belongs to the regional trend of the deep NE-SW Cap Serrat - Gardimaou fault system with volcanic occurrences (Laridhi, 1988a; Laridhi et al., 2004).

In north-western Tunisia, the emplacement of the dense Numidian thrust belts, forming a thick overburden and serving as Cap-rock for the underneath reservoirs, is exerting lithostatic pressure over the series below (fig.15). This subsiding context is favourable for the source rocks "cooking" and maturation. At the same stage, the reservoir quality is improved by the genesis of supplementary pore spaces by burial solution processes (fig.16).

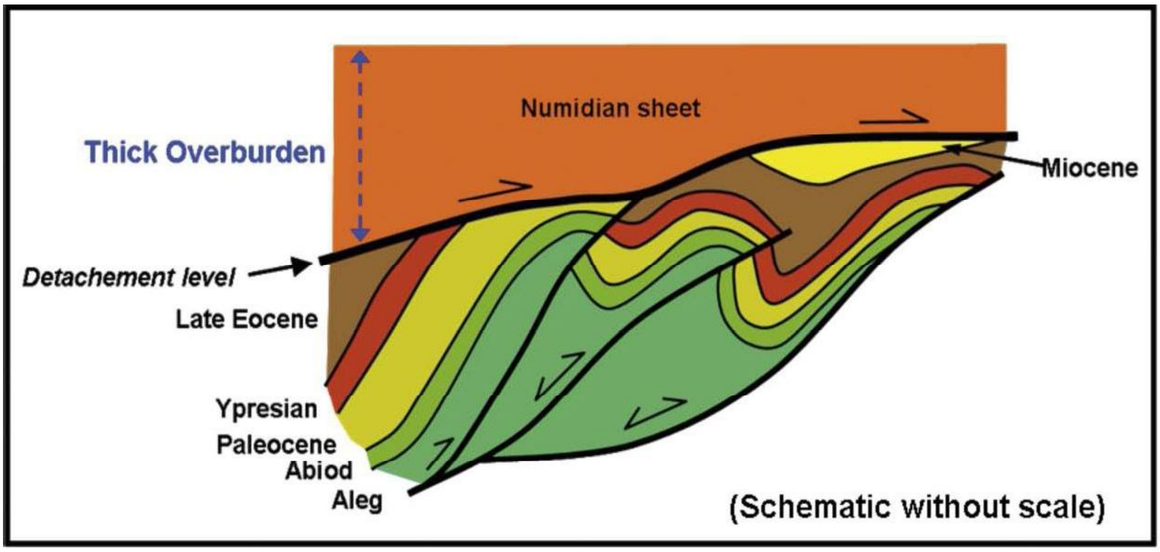

Fig.15. Thick Numidian sheets forming good overbureden and lithostatic pressure for the underneath reservoirs and source rocks

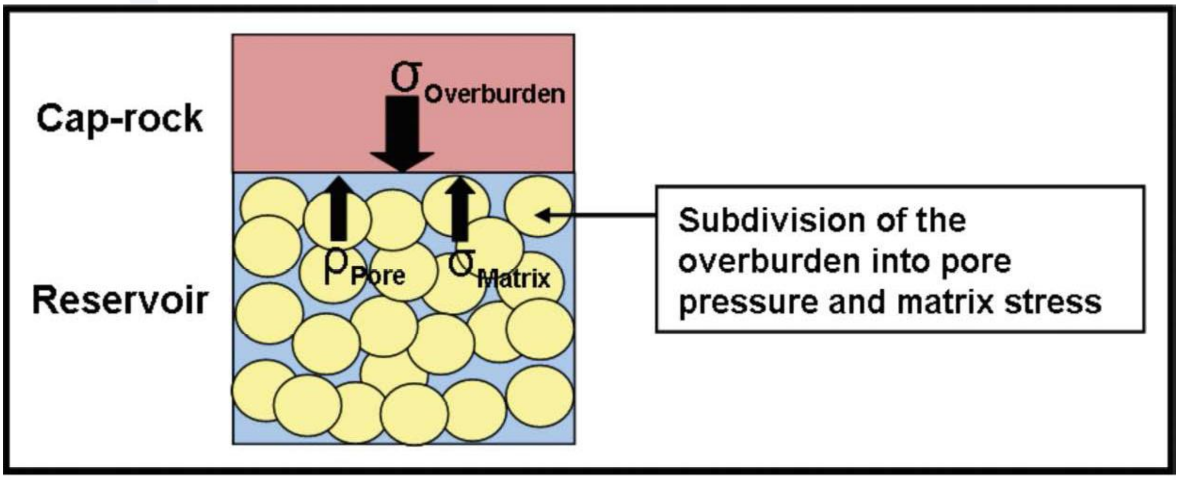

Fig.16. Bulk stresses generated inside the reservoir facies by the overburden load of the cap rock

5. CONCLUSIONS

The present confirms the idea that exploring for hydrocarbon under thrust belts is a challenging new frontier in northern Tunisia. In fact, the Pre-Ypresian morphology on which are deposited the Early Eocene Bou Dabbous well-bedded pelagic limestones, has a direct impact on local facies changes, diagenetic modifications and secondary pores creation. Moldic and vuggy pores, for example, which appear closed to stylolites and other compaction features, are more likely to have formed in a subsiding area, during burial diagenetic phases than during sub-aerial exposure. As shown in other settings, burial fluids flow related to the salt, associated in our case with thrust tectonics increase the heat flow and lithostatic pressure, consequently the behaviour of the carbonate series. Created pores which occur within the micritic matrix can be added to those associated to the fracturing.

On the other hand, in addition to the identified reservoir characteristics, source rocks are also available and proven since most pores exhibit hydrocarbon shows. Source rocks maturity and hydrocarbon expulsion appears favoured by the geodynamic subsiding context.

All this facts will provide a supplementary interest to the northern Tunisia in terms of petroleum system and potentiality.

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