The Eocene Gir Formation of the Ghani and Ed Dib Fields, Eastern Libya -An example of "Virtual Core Study"*

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Summary

The Gir Formation of Eocene (Ypresian) age comprises a 500-1000m sequence of carbonates and evaporites deposited in a shallow shelf to lagoonal setting along the North African Tethys margin. Depositional setting and lithology vary both laterally and vertically. In the eastern Sirte Basin, the Gir is composed almost entirely of shallow-marine, fine-grained limestones of the Mesdar Member. In the central and western Sirte Basin; however, it is divided into three members; here the top Mesdar Member overlies a thick, predominantly evaporitic Hon Member, which includes subordinate but widespread dolomite interbeds. The basal Gir interval includes coarser grained carbonates assigned to the Facha Member.

In the Ghani and Ed DIb fields, reservoir potential exists within both the upper Facha and lower Hon members, while the upper Hon is used as an aquifer source for Power Assisted Dump Flooding (PADF). Detailed core analysis, combining core description and Conventional Core Analysis (CCA), revealed tremendous variation in dolomite reservoir quality due primarily to grain size that could not be reliably recognized from petrophysical analysis. Porosities in both poor and good reservoir averaged 25-30%, but with contrasting permeabilities, averaging <3mD in the poor and 50-500mD in the good quality dolomites. Porosity-permeability transforms were calculated using core data for all potential reservoir units and subunits with core data, and these were applied in combination with RFT mobility data in order to populate the subsequent modelling process. The work demonstrated that 70% of dolomites previously considered to be reservoir have little or no mobility and thus no reservoir potential, and permitted refined and more reliable calculations of oil in-place and producible reserves. These will be applied to the Field Development Plan of Ed Dib, which at present estimates contains approximately 1.5 billion barrels in-place and 225 million barrels recoverable reserves.

Introduction and Methodology

As part of the construction of a static and simulation model of the Ed Dib Field in the Sirte Basin of eastern Libya, it was necessary to incorporate a detailed core study in order to understand reservoir deposition and quality. As this work was conducted during 2011 and early 2012, it was impossible to conduct direct examination of the cores. Fortunately, Suncor had a good database including not only graphic core logs, CCA, and SCAL but also high quality photographic and core scan images of core from several wells that provided similar data that could have been achieved via "hands-on" examination. The observation and conclusions incorporated within this study were, therefore, achieved using only "virtual", digital data, and these were also be used for display purposes during the Core Conference.

Geological Setting and Depositional Environment of the Gir Formation

Pre-Cretaceous rifting and continental collisions controlled the development of predominantly NW-SE-oriented basement structures underlying the Sirte Basin, many of which were reactivated during subsequent tectonic episodes (Figure 1). The Sirte Basin initially developed as an intracratonic rift system with a horst and graben syn-rift structural architecture. Rift activity decreased during the Late Cretaceous and basin-wide sag (presumably due to thermal subsidence) became dominant, continuing into the Paleocene and Eocene.

The carbonate-rich shales of the late Paleocene/earliest Eocene Kheir Formation were followed by carbonates and evaporites of the Ypresian Gir Formation (Figure 2). The lowest Gir member, the Facha Member, represented onset of carbonate deposition within shallowing-upwards conditions, passing from marine muddy limestones in the lower part to peritidal, microcrystalline dolomites and anhydrites in the upper. Above the Facha, the Hon Member is a thick sequence dominated by anhydrites, with occasional microcrystalline dolomites and variably developed halite. The dolomite interbeds of the Facha and Hon members throughout the En Naga area and adjacent regions indicate a shallow, restricted hypersaline lagoonal environment with occasional flooding events during times of high sea level stand leading to dolomite deposition. The widespread, readily correlatable nature of the thin dolomite sequences (Figure 3) probably indicates the presence of a shallow lagoonal embayment over 600km long and 150km wide, bordering the southern margin of the Tethys seaway to the north.

Hon Member Depositional Cycles

Lithologies within the Hon Member in the Ghani - Ed DIb area (Figure 2) include dolomite, laminated and nodular anhydrite plus locally developed halite. Dolomitization was almost certainly early. The anhydrite would have originally been precipitated as gypsum but would have been replaced by anhydrite through water loss soon after burial.

The Hon Member comprises numerous cycles (>50) related to sea level fluctuation and salinity (Figures 2 and 3). The cycles contain at least four main facies including peloidal dolomudstone, bioturbated dolopackstone, laminated anhydrite, and nodular anhydrite (Figures 3, 4, 5, and 6). The beginning of the cycle is marked by peloidal dolomudstone, variably laminated and locally bioturbated, that was deposited in a shallow lagoonal environment with elevated salinity based on the restricted fauna. Burrows must have been made by a low-diversity infauna able to survive such conditions. Peloids may have originated from brine shrimp which can thrive in this kind of setting. Despite having porosities that reach over 30%, permeabilities in the peloidal dolomudstone rarely exceed 3mD. The bioturbated dolowackestone has porosities that reach over 30% and high core permeabilities, up to 500mD, and forms the most productive reservoir. Based on the coarser grain size and fragments of a more diverse faunal assemblage including bivalves and echinoderms, this sediment was probably deposited in a higher energy environment with normal or only slightly elevated salinity. Disseminated anhydrite occurs locally within both this and the bioturbated dolomite facies, which further reduces permeability.

The top of each complete cycle is marked by laminated anhydrite, commonly overlying alternating laminated anhydrite and dolomudstone and nodular anhydrite. This would have originally been precipitated as gypsum under hypersaline, subaqueous conditions. There must, however, have been limited connection to more fully marine waters, probably via seepage reflux across the lagoonal barrier, in order to permit mineral replenishment and thick, continuous evaporate deposition.

Minor occurrences of nodular ("chickenwire") anhydrite would have originated as gypsum nodules forming within the dolomitic sediment, probably during periods of exposure. Other evidence of occasional exposure includes the presence of dessication cracks, with longer periods of exposure and dissolution indicated by probable paleokarst features (Figure 7), such as brecciation and rubble zones (which may have enhanced horizontal permeability in the reservoir). Rip-up clasts of laminated dolomudstone and rare cross-lamination may have been formed during storm events.

Conclusions

Despite initial reservations, it proved possible to make detailed interpretations of reservoir deposition and quality using only digital core images and other digital data. This proves the importance of making high quality digital core photographs, including detailed close-up images, of slabbed core, especially when working on areas with remote or limited access. The study has permitted refined and more reliable calculations of oil in-place and producible reserves for the Ed Dib Field and will allow a more structured and efficient approach to future field development.

Acknowledgements

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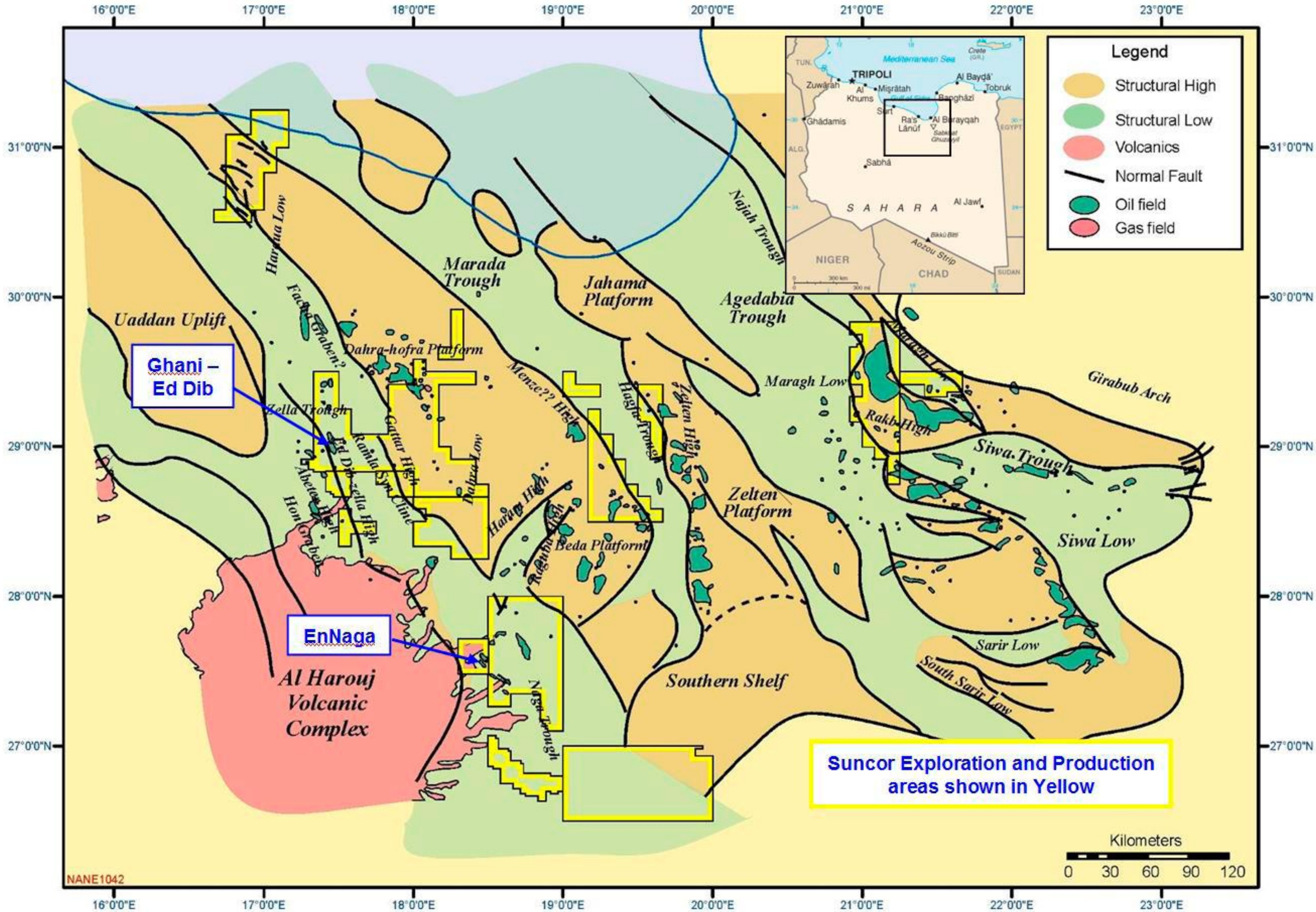

Figure 1: Sirte Basin showing major structural features and location of study area.

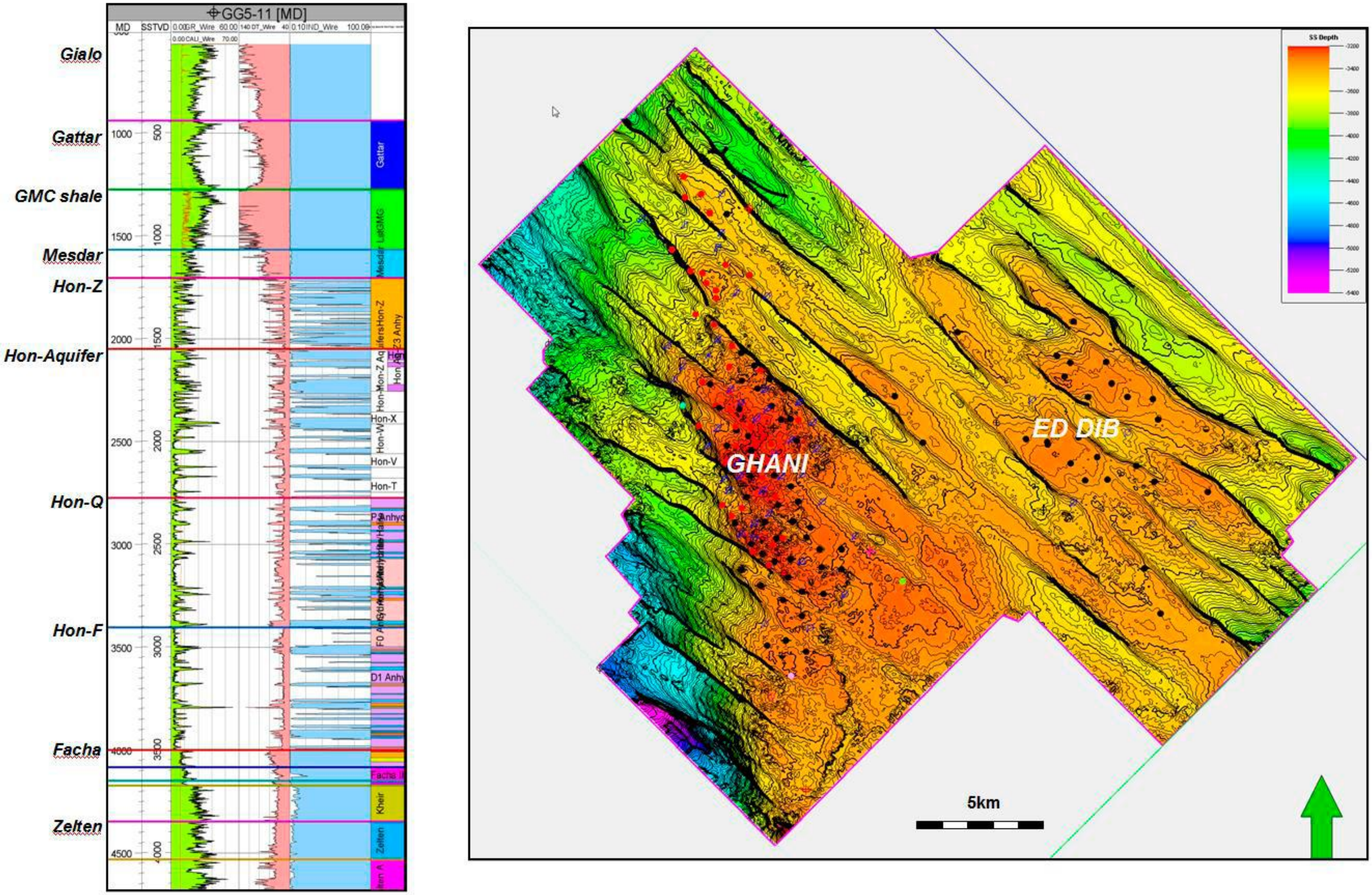

Figure 2: Late Paleocene-Eocene stratigraphy and Facha structure map of the Ghani and Ed Dib fields.

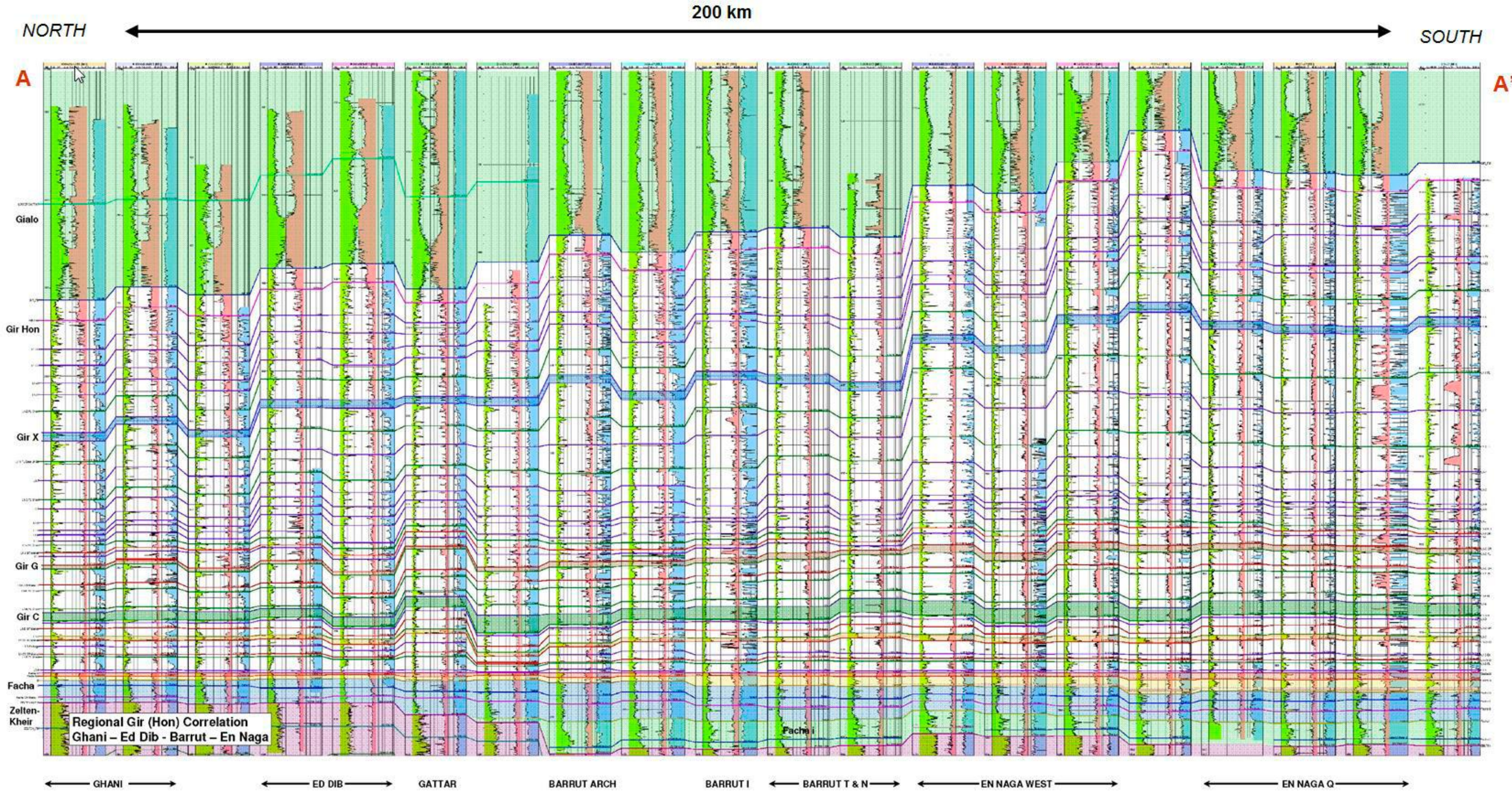

Figure 3: Regional correlation of the Gir Formation showing continuity of depositional cycles.

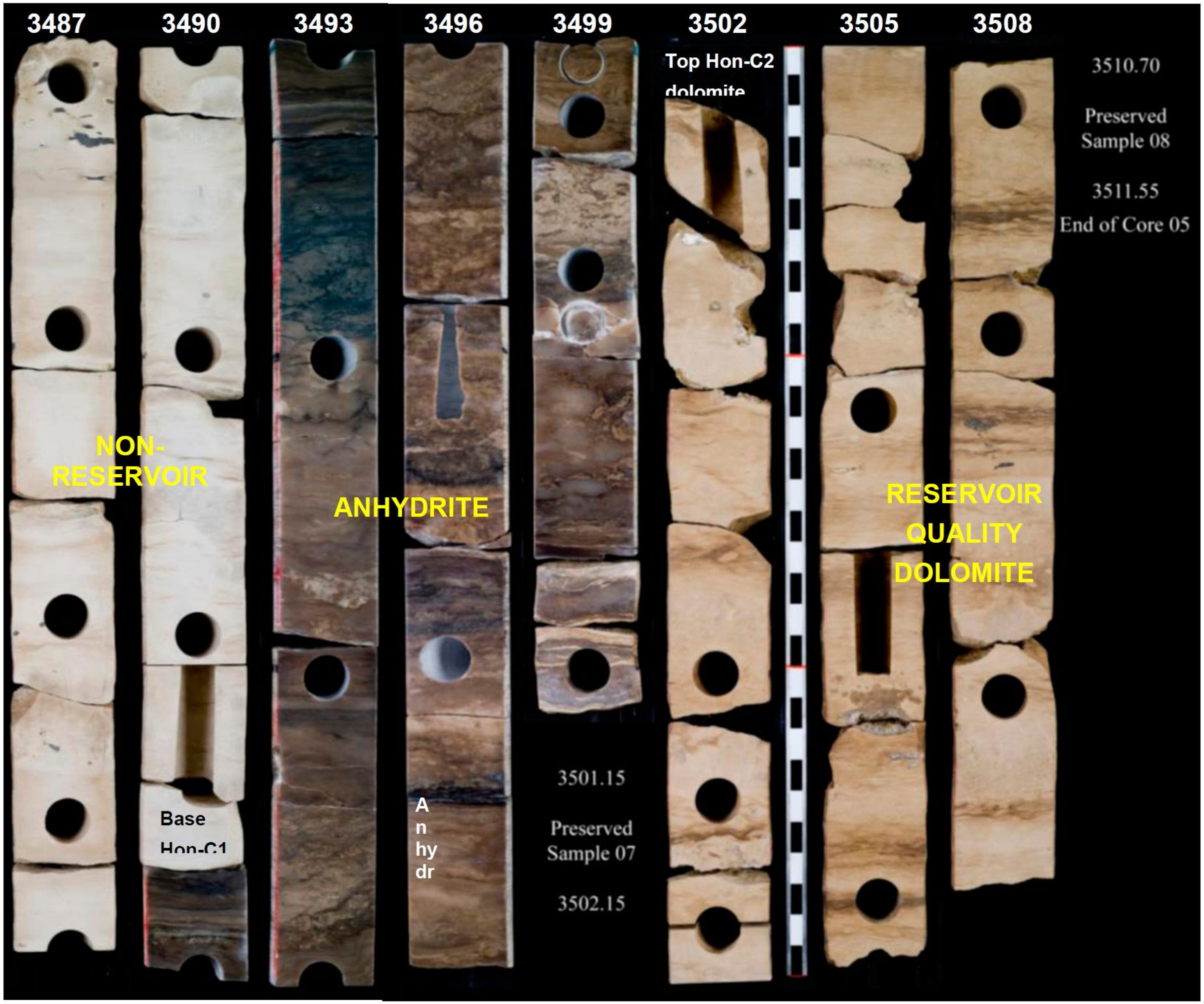

Figure 4: Typical Hon lithologies from Ed Dib Field (Hon C1-C2, well GG18-11).

- **Laminated anhydrite**
  - Subaqueous, hypersaline deposition in lagoonal setting (would have originally been gypsum)

- **Nodular anhydrite**
  - Probable intra-sediment formation (secondary replacement of gypsum)

- **Mottled, bioturbated dolowackestone**
  - Intertidal to subtidal deposition (lagoon or restricted ramp)
  - High macroporosity (can be >30%), high permeability (can be >100mD)
  - Best reservoir lithology in Units 4-5

- **Laminated/peloidal dolomudstone**
  - Elevated salinity lagoon
  - High microporosity (can be >30%), low permeability (<10mD)
  - Reservoir lithology in Units 1-3

Figure 5: Summary of Hon lithologies.

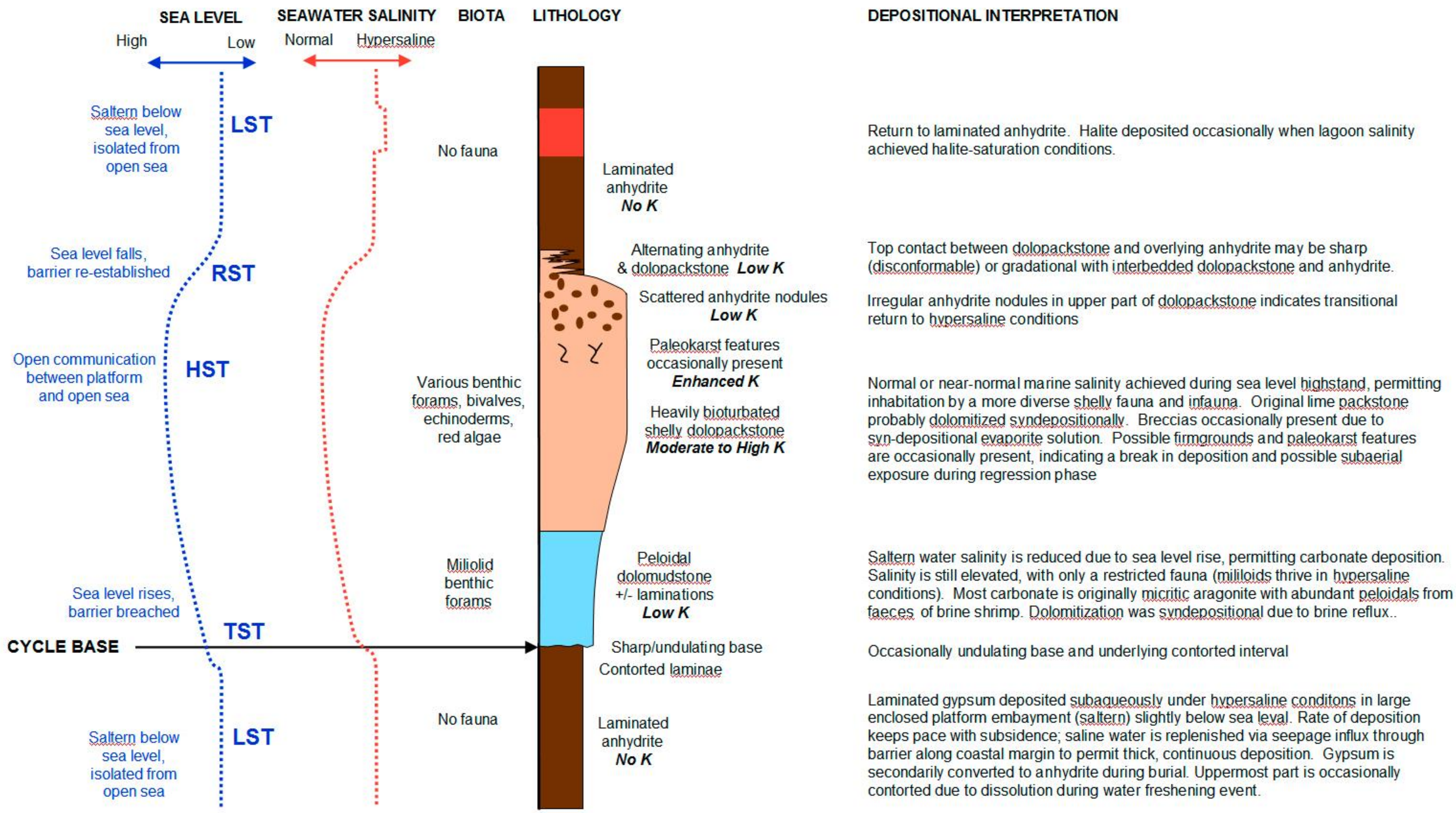

Figure 6: Schematic Hon cycle.

Paleokarst solution fracture and brecciation. Fractures are mostly infilled by anhydrite.

Dewatering fracture beneath ?firmground. Fractures are infilled by anhydrite.

Figure 7: Paleokarst features in the Hon and Facha members.