PS Characterization and 3-D Modelling of Reef Buildups and Associated Facies in a Kimmeridgian Carbonate Ramp System (Jabaloyas, Eastern Spain) as Analogue for the Middle East Arab D Formation*

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Abstract

Reservoirs from the Middle East are some of the most important hydrocarbon sources worldwide. Arab Formation (Upper Jurassic), and specifically Arab-D, is one of the representative reservoirs which shows some facies complexities and heterogeneities to overcome. Thereby, this key aspect in exploration and production led us to study an Upper Kimmeridgian analogue exposed in NE Spain: a low-angle carbonate ramp that includes the development of reef buildups formed by colonial forms (corals, stromatoporoids), and microbial crusts with associated encrusting organisms.

The well-exposed outcrops around the Jabaloyas village (Eastern Spain) have been used for a precise facies and sequential reconstructions within a 16-22 m thick high-frequency sequence. These outcrops show strike and non-strike sections across a 12 km^2 area (i.e., 4 x 3 km). The studied sequence is bounded by discontinuities that are traceable across a total of 17.5 km lineal distance and encompasses the coral-microbial buildups 5 to 15 m high (many of them with pinnacle morphology), developed in mid-ramp setting during the stages of maximum accommodation gain. Two hundred seventy-four reefs have been mapped across the different reconstructed 2D transects. Density calculation resulted in a minimum average distance of 50 m between the buildups, although there is a recognizable spatial distribution trend along the studied area. Seventeen stratigraphic profiles were carried out to control vertical and lateral facies distribution. The facies follows an overall retrogradational-progradational trend, with the development of low-energy peloidal-skeletal wackestones-packstones in the middle part of the sequence. Different types of grain-supported facies (ooidal, peloidal, intraclastic, skeletal) are found in both high-energy mid-ramp domains and inner ramp areas.

The field data were used for further 3D modelling. The overall distribution of the main facies were included in a full-field model (20 x 20 m grid increment) while the geometry, size and distribution of the reefs were better adjusted in sector models (1 x 1 m). These models assess the distribution of reservoir bodies and the connectivity. They will be used as a template for further diagenesis modelling and constitute the geological input for dynamic phenomenology using real field data set.

Characterization & 3D Modeling of Reef Buildups & Associated Facies in a Kimmeridgian Carbonate Ramp System

(Jabaloyas, Eastern Spain)

as Analogue for the Middle East Arab D Formation

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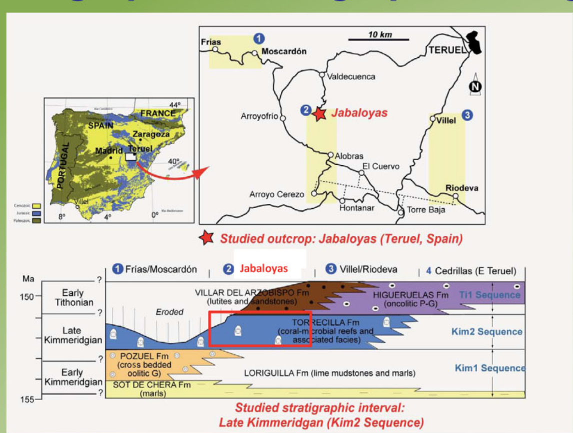
10th Middle East Geosciences Conference and Exhibition

Objective

Better assessing the sedimentary heterogeneity of the Arab D reservoirs by studying the vertical and lateral facies distribution in a well-exposed stratigraphic analogue outcrop.

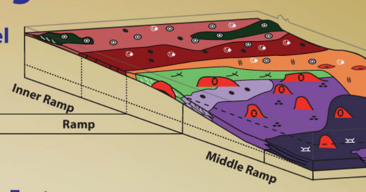
Geographic & Stratigraphic setting



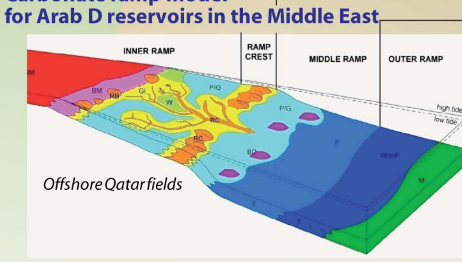
Paleogeographic setting

Analogue for Arab-D Fm

Carbonate ramp model for Jabaloyas Outcrop

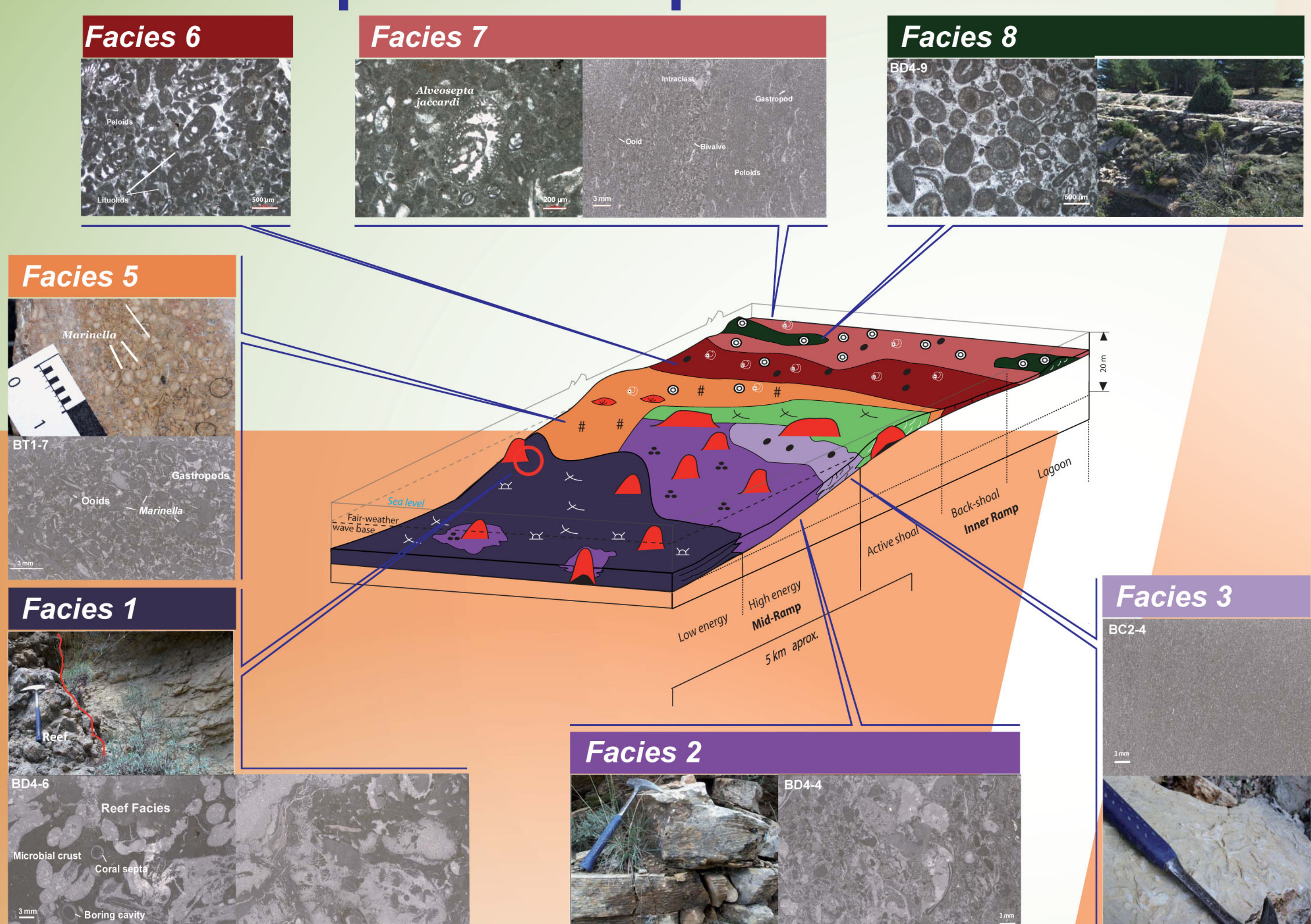


Carbonate ramp model for Arab D reservoirs in the Middle East



A Anhydrite
BM Boundstone – Microbial dominated
BC Boundstone – Cladocoropsis dominated
RB Rudstone – Bioclast dominated
RC Rudstone – Cladocoropsis dominated
Gl Grainstone - horizontal lamination
M Mudstone
W Wackestone
mP microPackstone
P Packstone

Facies description and depositional model



Reefs **CORAL-MICROBIAL BOUNDSTONE**
Colonial organisms (up to 90% of the components)
Main corals: *Thamnasteria, Cosmoseris and Microsolena.*
Accessory corals: *Calamophylliopsis, Stylina excelsa, Ovalastrea delgadoi, Milleporidium formosum, Axosmilia infundibuliformis, Ovalastreadelgaodi*
Others: Stromatoporoids, chaetetids, sponges, solenoporacean algae, bivalves and echinoderms
Microbial crust (10-80%): dense micritic and peloidal fabric, and associated encrusting organisms (serpulids, bryozoans, Koskinobullina, Lithocodium, Tubiphytes, Bacinella)

1 BIOCLASTIC WACKESTONE-PACKSTONE
Tabular to irregular (nodular) limestone beds (up to 0.4 m thick), interbedded with cm- to dm- thick marls
Cemented beds rich in large bioclasts forming "aprons" around the reefs (i.e., rudstone and floatstone textures).
Dominant: cm-size bivalves (including ostreids), echinoderms and corals.
Accessory: gastropods, solenoporacean algae, chaetetids and foraminifera (lituolids). Irregular lithic peloids and intraclasts corresponding to small-size debris of microbial crusts.

2 INTRACLASTIC-BIOCLASTIC PACKSTONE-GRAINSTONE
Tabular to irregular beds (up to 0.4 m thick) with frequent hummocky cross-stratification and cross-bedding
Reef-derived intraclasts (up to 90% of the components). They are up to 5 mm in diameter and mostly correspond to fragments of microbial crusts and reworked micrite.
Peloids may be present up to 50% of the components.
The **bioclasts** (up to 70% of the components) are bivalves, echinoderms and serpulids. Less frequent are corals.

3 PELOIDAL GRAINSTONE-PACKSTONE
Tabular to irregular beds (up to 0.5 m thick) with frequent cross-lamination and local hummocky and planar cross-bedding
Planolites trace fossils are common.
Well-sorted lithic peloids may form up to 90% of the components. They are ovoid and irregular in shape and up to 0.2 mm in diameter.
Bioclasts (up to 20%) consists of bivalves, echinoderms and foraminifera (lituolids, miliolids and textularids).
Type-1 ooids may be locally present (up to 20%). They are ovoid and spherical in shape and up to 0.7 mm in diameter.

4 BIOCLASTIC-OOLITIC PACKSTONE-GRAINSTONE
Tabular to irregular beds (up to 0.3 m thick) with local planar cross-bedding and channelized base
Skeletal grains (up to 70% of the components) from bivalves, corals, solenoporacean and chaetetids.
Type-1 ooids (up to 1 mm in diameter) may form up to 60% of the components. They are mainly superficial ooids, with spherical to ovoidal shapes.

5 OOLITIC PACKSTONE-GRAINSTONE with Marinella
Irregular beds (up to 0.4 m thick) with local planar cross-bedding
Type-3 and 4 ooids: The cores of these ooids are miliolids, lituolids, algae, equinoderms and quartz grains. Peloids and aggregates are also occasionally found.
Other skeletal components are gastropods and bivalves.
Foraminifera (miliolids, textularids and lituolids), Cayeuxia, echinoderms and solenoporacean algae are less abundant.

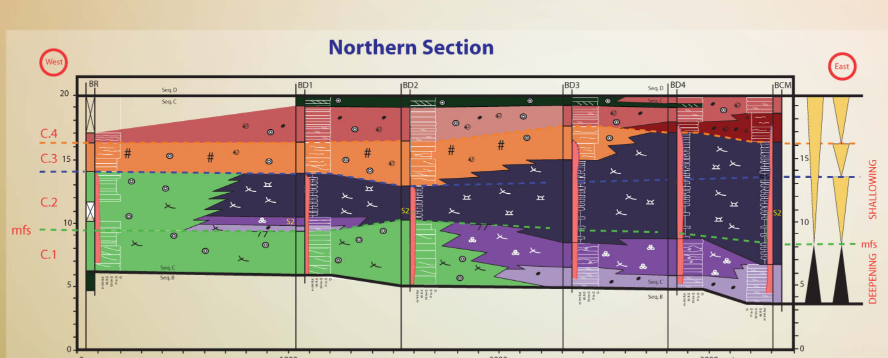
6 PELOICAL-OOLITIC PACKSTONE-WACKESTONE
Bioturbated tabular beds up to 1.3 m thick
Ovoid and irregular peloids (up to 70% of the components) up to 0.4 mm in diameter.
Ovoid and spherical **type-3 and -4 ooids** up to 1 mm in diameter form up to 40% of the components.
Main bioclasts (up to 20%) are foraminifera (miliolids, *Nautiloculina oolithica*, lituolids, including *Alveosepta jaccardi)* and gastropods.

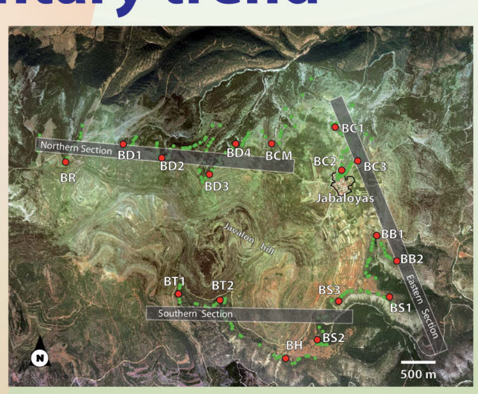
7 OOLITIC-PELOIDAL PACKSTONE-GRAINSTONE
Irregular beds up to 0.6 m thick with planar cross-lamination
Up to 50% of ovoid, sub-spherical and spherical fibrous radial **type-3 and type-4 ooids**, up to 1 mm in diameter.
Peloids (up to 45%) are irregular, ovoid and spherical and are up to 0.4 mm in diameter.
Bioclasts are dominated by bivalves and foraminifera (miliolids, lituolids, Lenticulina, textularids).
Type-II oncoids, aggregates, compound ooids and quartz grains are occasionally found.

8 OOLITIC GRAINSTONE
Tabular beds (up to 0.5 m thick) with frequent planar cross-bedding
The ooids (up to 95% of the components) are spherical, up to 1.5 mm in diameter. Type-3 and type-4 ooids are found in larger proportion than high-energy type-1 ooids.
Gastropods and foraminifera (miliolids and lituolids) are often found surrounded by incipient oolitic coatings. The bioclasts are mainly bivalves.

Reconstruction of the different facies belts from the sedimentological analysis indicates:
- no clear evidence of deposition in intertidal environments. All the described facies have been interpreted as deposited in subtidal environments, in an almost pure carbonate system. The siliciclastic input in Sequence C is very low and sand-size quartz grains are restricted to the nuclei of the different types of ooids. Occasional quartz concentrations in distal facies were possibly caused by storm-induced density flows.
- a progressive transition from proximal Facies 6–8 deposited in interior platform areas (i.e., protected lagoon) to relatively open marine domains (i.e., proximal mid-ramp) represented by the mud-dominated Facies 1.
- a development of the buildups mostly in the mid-ramp domain. This is based on observed relationship between the coral-microbial buildups and the coeval inter-reef Facies 1–4. Some smaller size patches or biostromes were coevally developed to the Marinella Facies 5 in inner ramp areas.

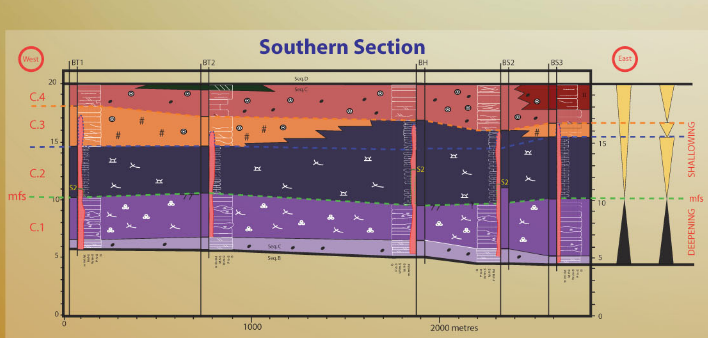
Facies distribution and sedimentary trend

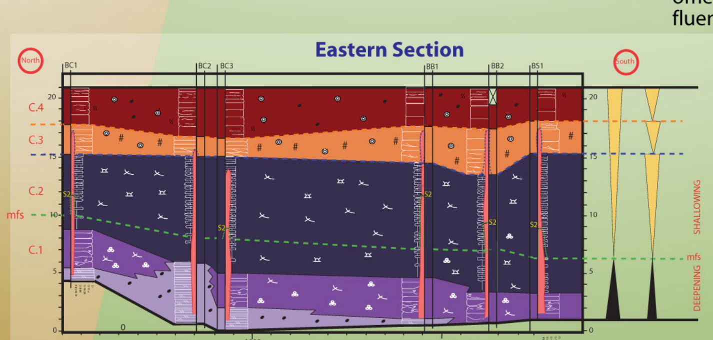


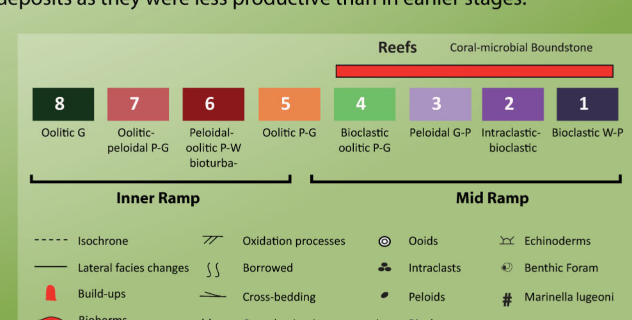


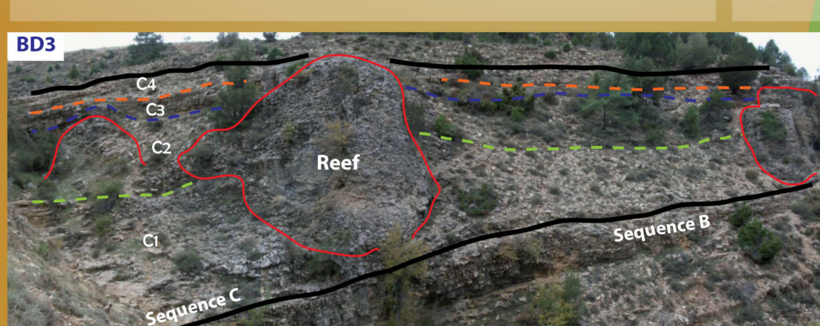
A complete geological study was carried out on the high-order sequence C outcrops within the 3rd order Kim2 sequence, in the Jabaloyas outcrops (12 km^2). Detailed geological mapping of the sequence allowed the recognition of 274 reef buildups (green points). A total of 17 sedimentological profiles (red points) were done through every gully ("barranco") of the zone. The profile thickness varies from 12 to 20 m.
The Northern and Southern correlation panels show the facies distribution from proximal to distal ramp areas, whereas the Eastern correlation panel is almost parallel to the defined facies belts.

Sedimentary Trend
The thickness of the Sequence C varies between 12 (stratigraphic profile BR) and 20 meters (BB1) and Facies analysis on sequence C has allowed the recognition of four sedimentary stages: C1 to C4.
C1 represents the **Transgressive Deposits** that is defined by the retrogradation pattern until the maximum flooding surface (MFS). This MFS consists of an encrusted surface, which in proximal areas is characterized by a sharp vertical facies change from grain-supported to mud-supported facies. Additionally, this surface correlates with an internal surface within the reef bodies, which reflects a period of slow growth of colonial forms and predominance of microbial crusts.
Early Highstand Deposits (C2) are dominated by sedimentation of low-energy offshore facies in most of the studied area, and the subtle progradation of shallow mid-ramp grain-supported facies in proximal areas. The **late Highstand Deposits (C3, C4)** are characterized by rapid progradation of the inner-ramp facies. Facies 6 invades the platform showing onlap geometries over the top of the pinnacles. During the late highstand, the reef buildups did not influence the inter-reef deposits as they were less productive than in earlier stages.

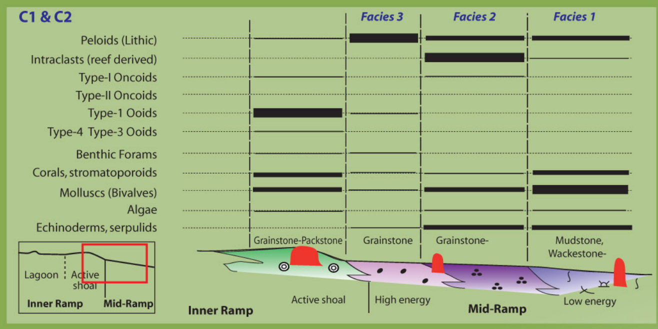


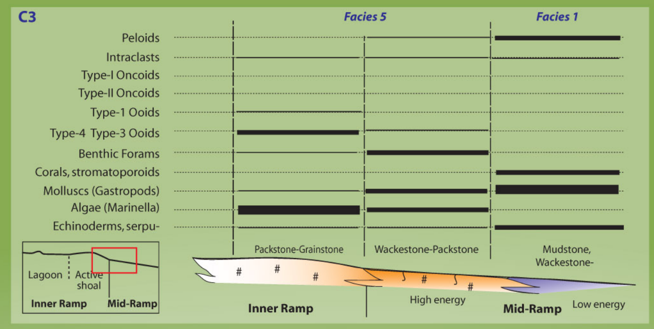


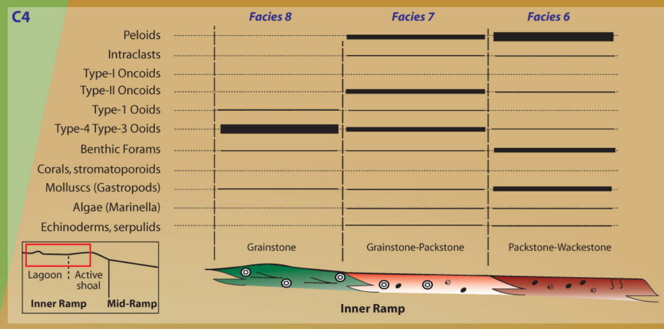


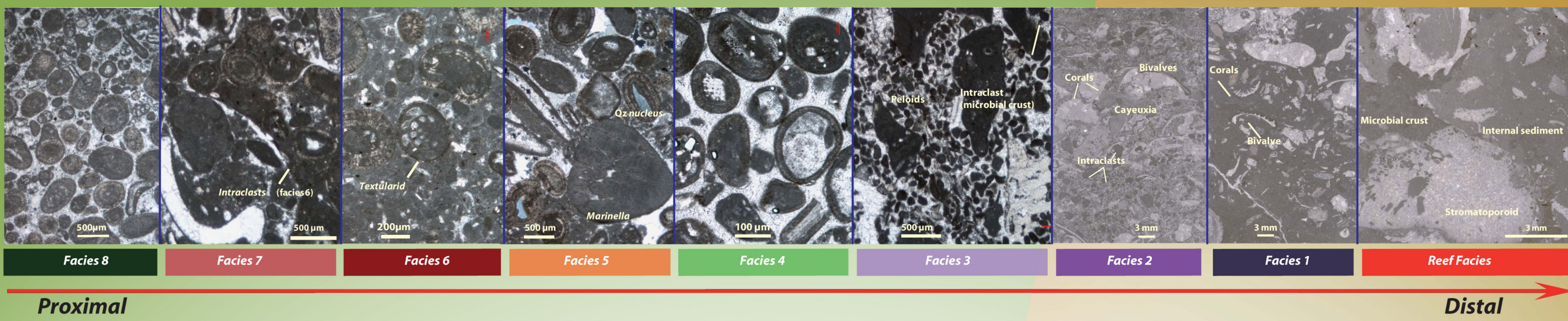


Facies models and carbonate grains









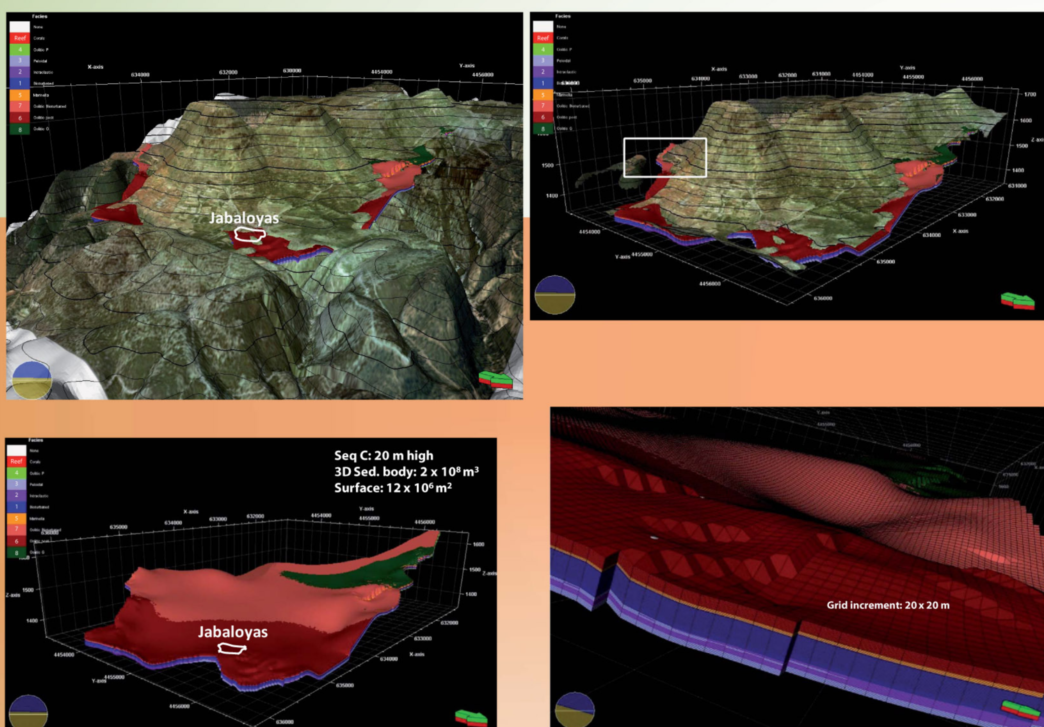
The relative proportion of carbonate grains in the different facies reveals a clear down-dip evolution.

- The C1 and C2 stages are dominated by type-1 ooids in proximal area passing gradually basinwards into peloidal-intraclastic facies. The reef-derived debris (peloids, intraclasts and skeletal grains) occurred along the entire profile coeval to the growing of coral-microbial reefs. The coral-microbial reefs grew from high-energy to low-energy mid-ramp areas, mostly during the stages of rapid increase of accommodation.
- Paleotopography created by coral-microbial reef development resulted in isolated paleohighs over the sea floor at the onset of stage C3, which was filled by *Marinella*-oolitic facies. The proximity of inner ramp domains is outlined by the abundance of sparitic ooids and benthic foraminifera. However, the *Marinella*-rich facies were deposited in open environments, as indicated by the gradual change to the offshore mud-supported Facies 1.
- Stage C4 marks the widespread progradation of the inner ramp Facies 6–8. Facies 6 represents quiet environments behind the active shoal with high proportion of lime mud. Peloids probably result from micritization processes in these quiet environments. A larger proportion of benthic foraminifera (lituolids, miliolids) and small gastropods is also found in this inner ramp setting. The sand bars consisting of Facies 7 and 8 are almost completely made up of type-3 and type-4 ooids.

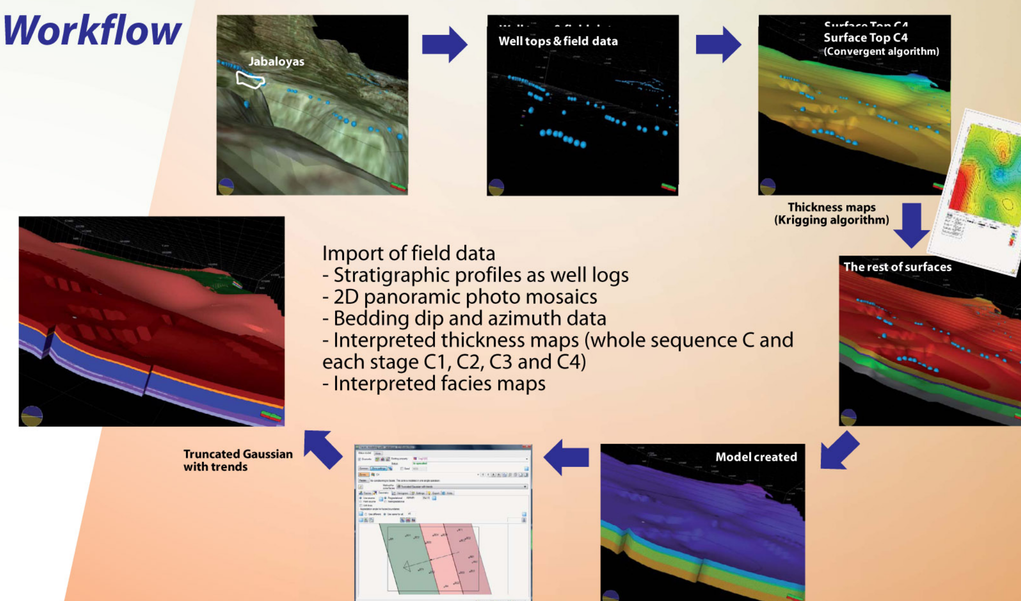
3D Modeling

Full field model

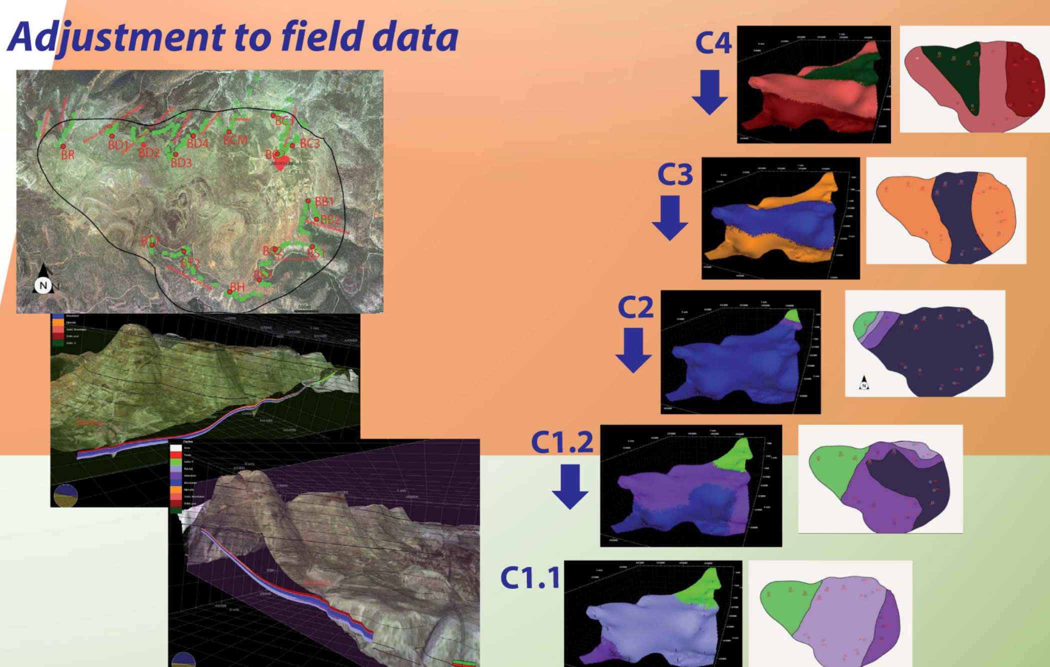
The outcrop data were integrated in a 3D geological model using Petrel software. Spatial distribution of facies deposited in a carbonate ramp has been visualized and reconstruction of the stratigraphic pattern has been confirmed.



Workflow

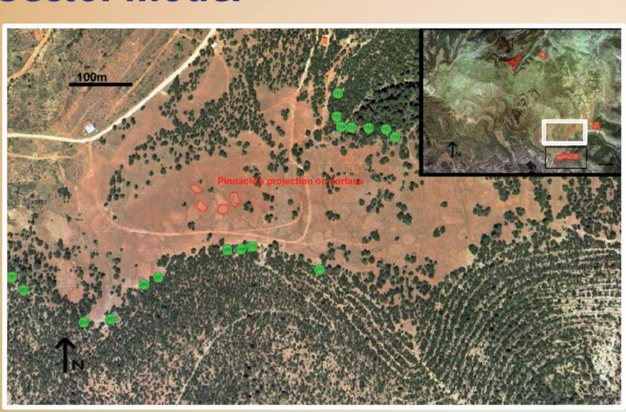


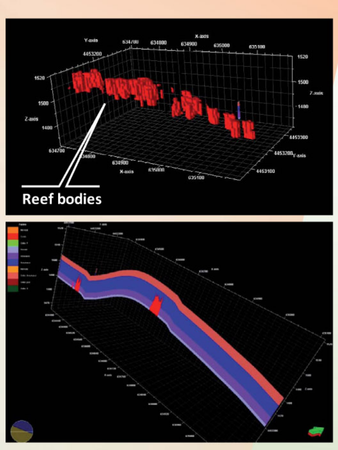
Adjustment to field data

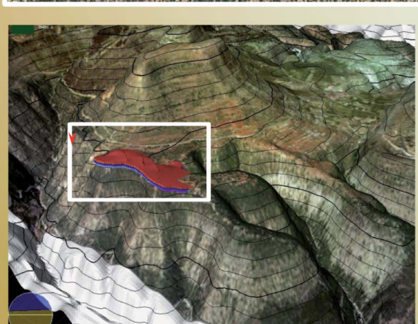


The top cemented bed is used as reference surface in the 3D model. The stratigraphic surfaces separating the successive stages in Sequence C were adjusted to some minor fault planes (not incorporated as 3D objects). Facies modeling was carried out with Truncated Gaussian algorithm with trends. The facies maps reconstructed from the field data were adjusted layer by layer during the performed simulation.

Sector model

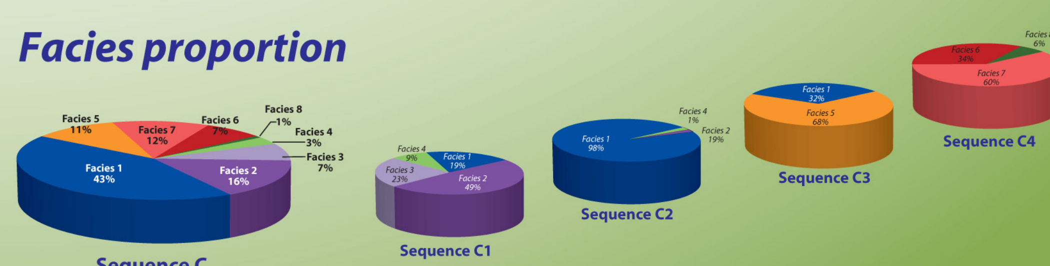






The grid increment in Petrel (20 x 20 m) for the facies belts was not suitable to include the small pinnacle reefs around Jabaloyas. As a result, a SECTOR MODEL was prepared for accurate modeling of the pinnacle distribution. The coral-microbial reefs of the selected area (white patches on the aerial photographs) are located between the BD and BS2 logs and correspond to the relatively distal ramp domains. The buildups have a relatively low spatial density, forming isolated pinnacle bodies up to 19 m high. Reef buildups have the spherical and elliptical geometries.

Facies proportion



Conclusion

The quality of Jabaloyas outcrops provides suitable field data for building 3D models of facies distribution within high frequency sequence stratigraphy.
Evolution of facies distribution has been reconstructed from thorough sedimentological interpretation of 17 field logs. Eight facies belts with different proportion of skeletal and non skeletal components have been interpreted in terms of proximal to distal ramp settings.
Two 3D geological models were built:
- **a full-field model allowing calculation of volume and proportion for inter-reef and post-reef facies. The resulted facies belts that have been reconstructed from field observations are approximately 1–2 km width.**
- **a sector model, where the reef bodies were incorporated. These models have been used as a template for further test on diagenesis overprint and resulting distribution of reservoir bodies and connectivity for sector simulation (phenomenology purposes) with real reservoir/field data.**

These well documented 3D models have contributed:
- **to better understand and quantify facies distribution in a subsurface Arab D reservoir,**
- **to reduce the geological uncertainties associated with facies heterogeneities in similar carbonate ramp reservoirs.**

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