BOEM 2012-088

Atlantic Well Folio: Georges Bank Basin

Lydonia Canyon Block 312 No. 1 Well

Erin T. Elliott
Paul J. Post

U.S. Department of the Interior
Bureau of Ocean Energy Management
Gulf of Mexico OCS Region
Office of Resource Evaluation

1.4. Lydonia Canyon 312-1

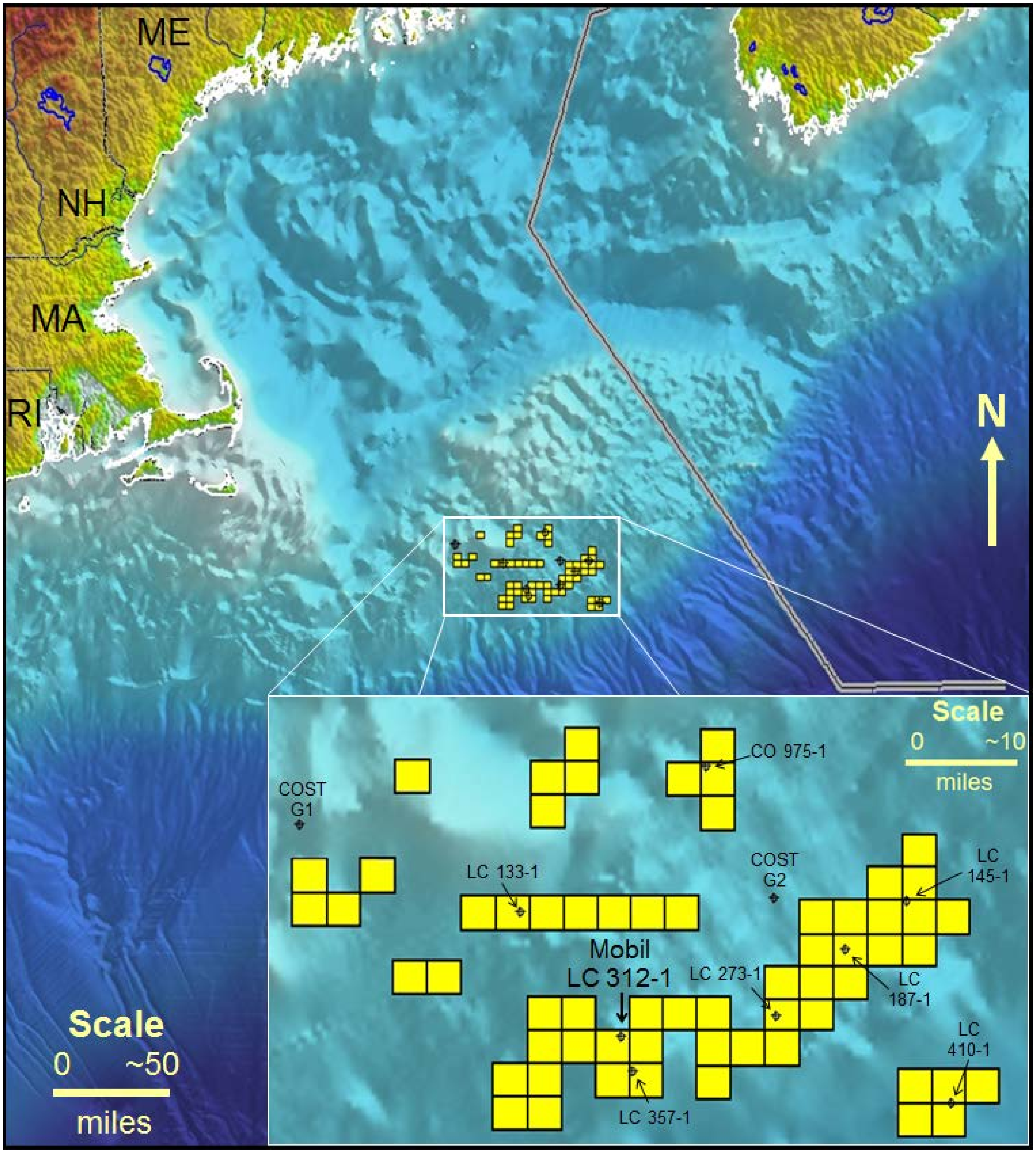

Figure 1. Location map of Georges Bank basin, offshore Massachusetts, USA. Well locations are indicated with ⌖. Leases previously held in the area are shown in yellow.

On December 8, 1981, Mobil (54%) spudded Lydonia Canyon (LC) 312-1, the fourth industry exploration well and sixth well drilled in the Georges Bank basin (GBB) (Figure 1, Table 1). LC 312-1 was drilled in 259 feet of water approximately 34 miles southeast of COST G-1 and 17 miles southwest of COST G-2. The *Rowan Midland* semisubmersible was used to drill the well. Total depth (TD) of 20,000 ft was reached June 12, 1982. The well was plugged and abandoned as a dry hole without hydrocarbon shows on June 27, 1982.

Table 1. Wells drilled in Georges Bank basin

Well	Date	Target	Actual
COST G-1	1977	n/a	n/a
COST G-2	1976	n/a	n/a
LC 133-1	1981	Callovian Reef	Volcanic Sequence
CO 975-1	1982	Bathonian porous shelf carbonate	Evaporite Lens
LC 410-1	1982	Porous Jurassic Limestone, Structural Closure	Jurassic closure poor porosity and permeability
LC 312-1	**1982**	**Callovian Reef**	**“Tite” micritic Limestone**
LC 187-1	1982	Jurassic age Limestones and Dolomites	Reservoir of poor porosity and permeability
LC 145-1	1982	Jurassic Porous Shelf edge Calcarenites and Carbonates	“Tite” micritic Limestones
LC 273-1	1982	Four way closure, Jurassic Oölitic and bioclastic limestones	“Tite” micritic Limestones
LC 357-1	1982	Simple structural closure in Limestone, Dolomite, and anhydrite	“Tite” micritic Limestones

1.4.1. Objectives and Concepts

The objective of LC 312-1 was to test the updip portion of a seismic anomaly interpreted as a Middle Jurassic (Callovian) reef (Figure 2).

Included with Mobil’s 1981 Plan of Exploration (POE) and Application for Permit to Drill (APD), submitted to the United States Geological Survey (USGS), were structure maps and pre-drill interpreted seismic lines. These, in addition to post-drill well logs, cores, and test results submitted by the operator and relevant literature were used in compiling this report.

Structure maps from Mobil’s APD (Figure 3) show an anomaly interpreted to be a Callovian reef as the target. The anomaly has a horseshoe shape and exhibits approximately 1,200 ft of relief. Seismic data was acquired and processed in 1979. In Figure 4, the original interpretation of the Base Oxfordian and L. JR MKR horizons are represented by teal lines and the interpreted reef, between 2.9 and 3.3 seconds two-way travel time (TWTT) and approximately 15,800 ft to 17,000 ft, is shaded in blue (Mobil, 1981). No information was provided on the type of hydrocarbon accumulation (oil, gas, or both) expected.

1.4.2. Results

Drilling

There was no lithologic data available above 540 ft MD. The lithology of LC 312-1 is detailed in Table 2.

A single 30 foot conventional core was cut from 15,810 ft MD to 15,840 ft MD, with 28.5 ft recovered. The core consisted of brown to gray limestone containing occasional oolites, calcite crystals, calcite filled vugs and fractures, traces of fossils, and pebbles. No fluorescence was noted, and petrographic descriptions of the core indicate very little to no visible porosity (Mobil, 1981).

Table 2. Lithology of in LC 312-1

Depth (MD)	Lithology
540’	Conglomerate with pebbles and fossils in a sandy matrix
630’	Fossiliferous mudstone
1,200’	Glauconitic sandstone
1,375’	Micaceous, fossiliferous mudstones interbedded with thin sandstones
2.375’	Argillaceous limestones and mudstones
4,775’	Calcareous mudstone and microcrystalline bioclastic limestone
5,400’	Sandstone interbedded with coal and mudstone
6,020’	Mudstones
6,100’	Sandstone interbedded with mudstones and thin coals
6,300’	Mudstones
6,950’	Mudstone with interbedded siltstone
11,300’	Limestone
11,500’	Mudstones
11,960’ – TD	Argillaceous limestone interbedded with mudstone and siltstone

Eighteen sidewall cores were cut between 8,090 ft and 12,108 ft MD. All cores were from shaley zones and used for biostratigraphic control (Mobil, 1981).

Neither the conventional core nor the sidewall cores were analyzed for porosity or permeability. Instead, the average porosity was calculated by USGS staff from wireline logs and ranged from 5% to 34%. The average porosity in and below the target depth of 15,800 ft MD was ~5% (Giordano, 1982).

Seismic Interpretation

Included with Mobil’s APD were four pre-drill 2D time-migrated seismic lines, Line MMG 35 is included as Figure 4. Two interpreted horizons, the Base Oxfordian and the L. JR MKR, are highlighted in teal. Two anomalies interpreted as reefs are outlined and shaded in blue (Figure 4). These anomalies were interpreted as reefs because of their resemblance to the hydrocarbon-bearing reefs in the Michigan basin. Like those reefs, these anomalies exhibit overlying stratigraphic thinning, discordant reflectors through the anomaly and a sag beneath it. Originally named the Narragansett reef complex, this group of anomalies was thought to have formed in a tight arc around the updip perimeter of an embayment as part of a shelf-margin carbonate complex. The Bahamian reefs are a modern day analog (Figure 5). A major regression was interpreted to occur in the late Middle Jurassic terminating reef growth. A subsequent marine transgression resulted in the deposition of limestones farther landward in the GBB (Mobil, 1981).

Figure 6 is a carbonate anomaly map created by interpreting the edges of the anomalies (dark green lines). The edges were then gridded and contoured to create the carbonate anomaly map. The blue to light gray regions are local highs and the locations of the carbonate anomalies. One of these anomalies was drilled by LC 312-1 and another, to the southeast, was targeted by the LC 357-1 well. Both wells were abandoned as dry holes and analyses indicated that the seismic anomalies were not reefs.

The target of well LC 312-1 is imaged by two 2D seismic lines, recently depth-converted and time-migrated (d-c, t-m) by Fugro Robertson (GeoSpec) (Figures 7, 8, and 9). The south–north seismic line (Figure 7) shows the target interval of the well between 15,000 ft MD and 16,000 ft MD. The overlying ‘base Bathonian horizon’ is relatively flat-lying; although it exhibits what may be compaction-related thinning over the anomaly drilled. Just beneath the ‘base Bathonian horizon,’ the sides of the original target are outlined by a dashed line. Figure 8 shows this in greater detail. Figure 9 is a west–east detail of a seismic line that shows the targeted anomaly. The underlying 'Base Jurassic horizon' exhibits some structural relief and dips slightly to the south.

Biostratigraphy and Palaeoenvironment

Biostratigraphic and palaeoenvironment information compiled from Giordano (1982) and Edson et al. (2000) is shown in Table 3. The reliability of biostratigraphic data is questionable, especially in the Jurassic, because of the possible re-deposition of indicator fauna in the shallow environment of deposition (Edson et al., 2000).

Most of the sediments in the LC 312-1 well were deposited in an inner to middle shelf environment (Table 3). Paleo-water depths were generally less than 300 ft, averaging approximately 110 ft (Edson et al., 2000). Present-day water depth is ~259 ft.

Interpretations from the conventional core indicate that carbonates in the objective interval were deposited in restricted and very shallow water, most likely intertidal to supratidal conditions and therefore subject to wave and current action. In the upper four feet of the core, disruption of lithified and thinly laminated sediment suggests episodic subaerial exposure. There was no evidence to suggest that the site had been in the vicinity or part of a reef (Mobil, 1981).

Table 3. Biostratigraphy and probable palaeoenvironment of sediment intervals in LC 312-1

Depth	Age	Lithology	Depositional Environment
0	Unknown	Insufficient data	Unknown
540		Laurentian: Conglomerate	Shelf (clastic, sand prone)
610	Miocene to L. Eocene	Banquereau Fm: Green silty mudstone and sandstone	Shelf (clastic, sand prone)
1375	Campanian to Cenomanian	Dawson Canyon Fm.: Micaceous fossiliferous mudstones interbedded with thin sandstones	Shelf (mixed clastic & carbonate)
2865	Cenomanian to Aptian	Logan Canyon Fm.: Limestone unit overlying Gray silty mudstones interbedded sandstones (Naskapi Fm.)	Mud dominated shelf
4775	Hauterivian to Tithonian	Roseway Unit: Microcrystalline, bioclastic limestones with interbedded calcareous mudstones	Shelf (clastic, sand prone)
5430	Berriasian-Tithonian	Mississauga: Interbedded sandstone, mudstone, and thin coals	Shelf (clastic, sand prone)
6910	Tithonian	Roseway Unit: Oölitic, fossiliferous, and micritic limestones	Shelf (carbonate dominated)
8100	Tithonian to M. Jurassic*	Mic Mac-Mohawk: Fissile mudstones interbedded with argillaceous siltstones, some micritic limestones	Shelf (mixed clastic and carbonate)
11960	M. Jurassic*	Abenaki: Oölitic and fossiliferous limestone with mudstone and siltstone	Shelf (mixed clastic and carbonate)
15270	M. to E. Jurassic*	Mohican: Oölitic and fossiliferous limestone with mudstone and siltstone	Shelf (mixed clastic and carbonate)
15390	M. to E. Jurassic*	Iroquois: Oölitic and fossiliferous limestone, locally anhydritic and dolomitic	Restricted shallow marine

E. – Early M. –Middle L. –Late

*Sediment interpreted as being reworked; therefore, age interpretation considered unreliable.

1.4.3. Operations and Costs

Mobil (54%), Amerada Hess Co. (25%), Tenneco Inc. (10%), Transco Exploration (6%), McMoRan-Freeport Oil Co. (3%), and Sohio Petroleum Co. (2%) leased block 312 for a high bid of $79,196,000 in 1979 at Sale 42 (Giordano, 1982), approximately $264 MM in 2012 dollars (HBrothers, 2012). The total well cost for LC 312-1 was estimated to be $35 MM (Giordano, 1982) equating to approximately $91.5 MM in 2012 dollars (HBrothers, 2012). This was a single block prospect. No cost breakdown was available. Total drilling time was approximately 195 days (from spud date to completion) including 13 days for a successful side track (after two failed attempts). Drilling operations were also halted for 20 days due to severe weather (Giordano, 1982).

1.4.4. Petroleum System Analysis

Magoon and Dow (1994) defined a petroleum system as “a natural system that encompasses a pod of active source rock and all related oil and gas and which includes all the geologic elements and processes that are essential if a hydrocarbon accumulation is to exist.” Petroleum is defined as biogenic or thermal gas located in a reservoir or as naturally occurring surficial condensates, asphalts, and crude oils (Magoon and Dow, 1994).

Essential geologic elements are: source rock, reservoir rock, seal rock, and overburden rock (a thick enough rock column above the source rock interval to result in burial sufficient for temperatures to trigger hydrocarbon generation). Our guidelines for source, reservoir, and seal elements are shown in italics in Table 4.

Essential processes include trap formation and hydrocarbon generation, as well as hydrocarbon expulsion, migration, accumulation, and preservation (Magoon and Dow, 1994).

Table 4. Petroleum System Elements

Element	LC 312-1 Lithology
Source rock *(>1% TOC)*	Limestones in the interval 6,000 ft- ~6,500 ft MD Shales at ~ 10,000 ft MD
Reservoir rock *(>10 % ϕ* *>1 mD k)*	Hauterivian sandstones (70% of mudstone-rich interval)
Seal rock *(10^{-3} mD k)*	Shale, impermeable limestones
Overburden rock	~10,000 ft above deepest source rock interval

The essential processes must act on the geologic elements at specific times such that a reservoir and trap exist, hydrocarbons are generated, expelled from the source rock, migrate into the trap, become entrapped and retained in the trap (Magoon and Dow, 1994). Not all processes will occur in all areas; *i.e.*, when there is no hydrocarbon generation and expulsion, there can be no migration or accumulation.

Geochemistry

The most widely used technique to establish the maturity of organic matter and its petroleum potential is Rock-Eval Pyrolysis. This technique involves heating a sample in a helium atmosphere (Pimmel and Claypool, 2001). The thermal maturation of a sample is determined by T_{max}, “the temperature at which maximum release of hydrocarbons from cracking of kerogen occurs during pyrolysis” (Pimmel and Claypool, 2001). Thermally mature rocks for oil generation are those that reach a T_{max} of ~435 ^oC (incipient/early mature for oil generation) and remain at or below 470^oC (post-mature for oil generation). For gas generation, T_{max} values must exceed 470^oC. Four basic products are obtained from Rock-Eval Pyrolysis: S1, S2, S3, and T_{max} (Pimmel and Claypool, 2001).

While TOC values of 1–2% are considered viable source rocks and will generate hydrocarbons, values near 1% TOC are generally considered inadequate contributors to the overall petroleum system (Jarvie, 1991). Source rocks that contain higher TOC and S2 values are better able to generate and expel hydrocarbons, which could then migrate into traps, or escape to the depositional surface via migration conduits.

In addition to Rock-Eval T_{max} values, vitrinite reflectance data are also used to determine the thermal maturity of a sample. These data provide a measure of the organic metamorphism applicable to different coal ranks or level of organic metamorphism (Table 5).

Table 5. Petroleum System Processes

Onset hydrocarbon generation	~7,000 ft MD based on vitrinite reflectance data.
Expulsion Migration Accumulation	Overall the well contains insufficient TOC (< 1%) to generate and expel hydrocarbons. There are no significant shows in reservoir lithology. This indicates that TOCs are too low to result in expulsion, *i.e*. the hydrocarbons are only in-situ (supported by BasinMod® *Classic* modeling) and/or a lack of vertical cross–stratal or other migration conduits to facilitate hydrocarbon expulsion, migration, or accumulation.

An analysis of Mobil's geochemical data in BasinMod® *Classic* shows that the T_{max} data points have a general increasing with depth trend from 419°C at ~800 ft MD to 482°C at ~19,000 ft MD. The vitrinite reflectance data seems to be reliable and also increase with depth. A good maturity regression is calculated using the reflectance values. Using the vitrinite reflectance data to model the thermal maturity of the well with BasinMod® *Classic*, onset hydrocarbon generation would occur at approximately 7,000 ft (Table 5).

Using an S2 vs. TOC diagram, the dominant kerogen type in the well is Type III and some Type II/III at approximately 6,000 ft subsea. TOC values for the LC 312-1 well ranged from 0.06% to a maximum of ~2.7%. Although coal was documented throughout the well, in sample descriptions and geochemical reports, a mud log was not available to confirm the depths of the coal or whether the intervals of high TOC were due to the presence of coal. TOC values between 1% and 2% were sampled in the Eocene Priabonian and Ypresian; LK Campanian, Santonian, Turonian, and Cenomanian; the EK Berriasian; and the LJ Kimmeridgian (a single sample of 1.31%, others below 1%). Samples with TOC between 2% and 3% (very good) were found in the LK Campanian and the EK Berriasian. The highest TOC values in the well occur in the Berriasian, between approximately 6,000 ft MD and 6,500 ft MD, making this the most likely source interval encountered in the well. However, according to BasinMod® *Classic* modeling, any potential source rocks above ~7,000 ft MD would be too shallow and immature to generate hydrocarbons.

Exploration Implications

The exploration implications derived from LC 312-1 are the following:

1. The source rock element was inadequate. Source rock richness (TOC) was generally insufficient (<1 %) to generate a significant amount of hydrocarbons or to allow the expulsion of hydrocarbons from the source rock. Based on geochemical modeling, any hydrocarbons generated are interpreted to remain in the source rock (Table 6).

2. The reservoir element of the petroleum system was inadequate. The interval containing the interpreted porous carbonate buildup (Narragansett reef complex) was of lower porosity and permeability than anticipated.

Table 6. LC 312-1 Target Summary

Pre-Drill Interpretation	
Target	~15,800-17,000 ft MD Interpreted Callovian Reef (Narragansett reef complex)
Trap Type	Structural-Stratigraphic
Hydrocarbon Expected	Oil or gas
Post-Drill Results	
Target Interval	At ~10,800 ft MD Jurassic carbonates were encountered. Insufficient TOC for hydrocarbon generation was encountered to TD of 20,000 ft
Hydrocarbon Shows	There were no reported shows of either oil or gas and no drill stem tests attempted. A mud log was not available.

Acknowledgements

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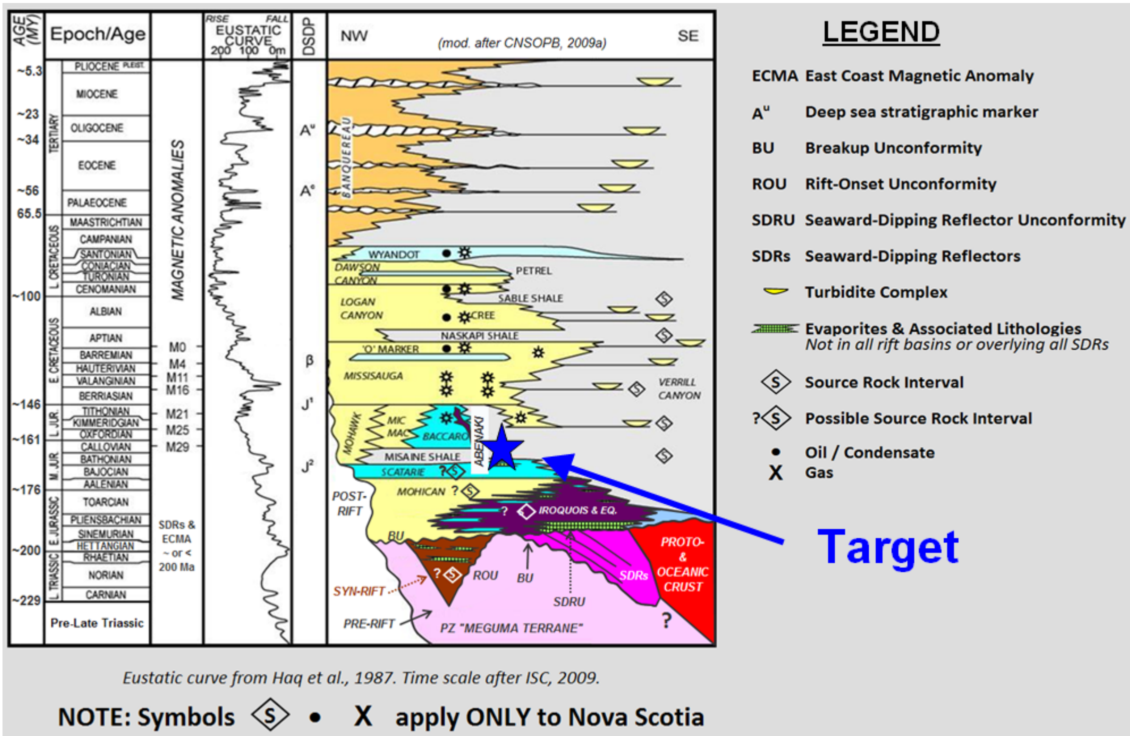

Figure 2. Stratigraphic chart showing the target interval for Mobil Well LC 312-1.

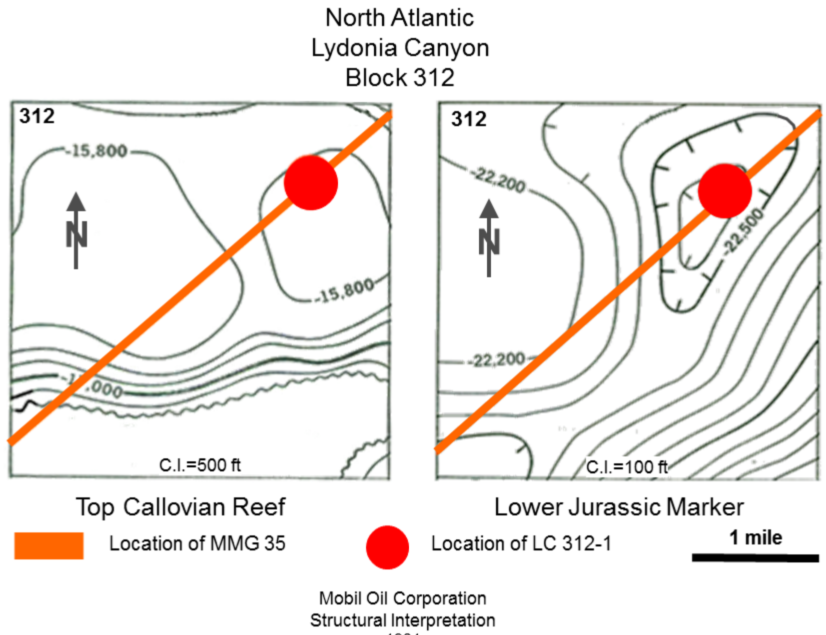

Figure 3. Mobil (1981) structure maps showing the top of the targeted Callovian Reef (Narangasett Reef Complex) and the base of targeted Jurassic carbonates.

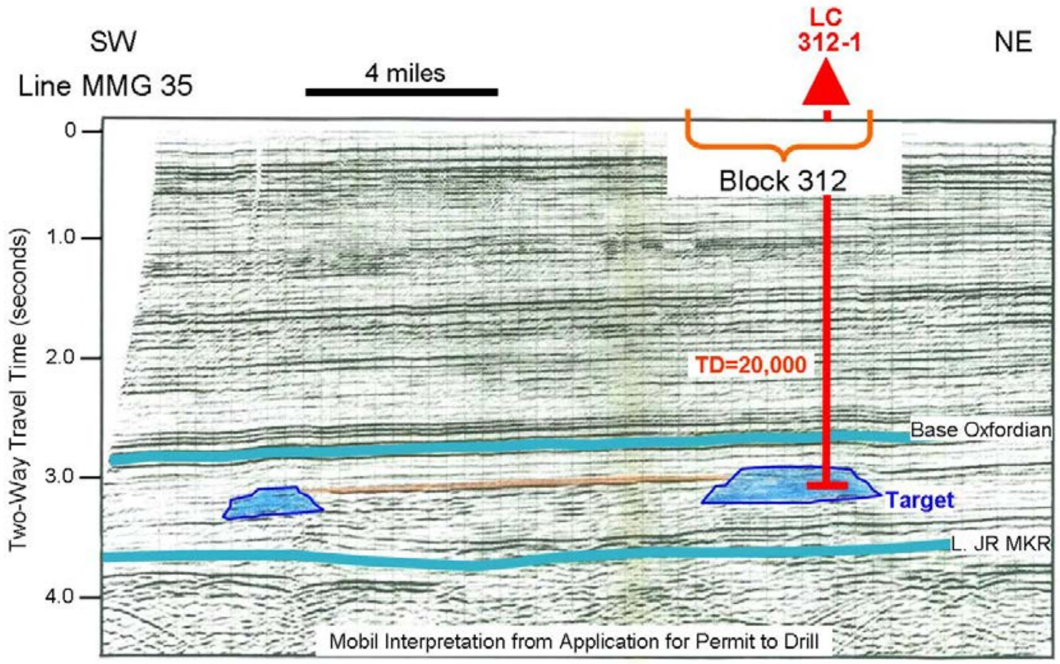

Figure 4. Mobil (1981) interpreted prospective Callovian reefs.

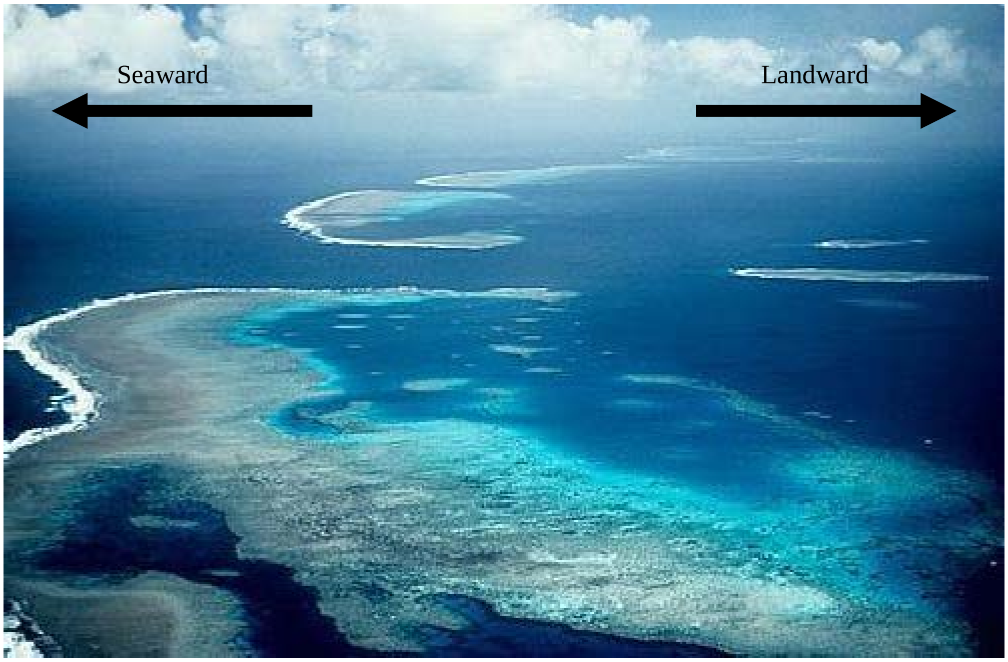

Figure 5. Modern day analog; carbonate reef complex in The Bahamas.

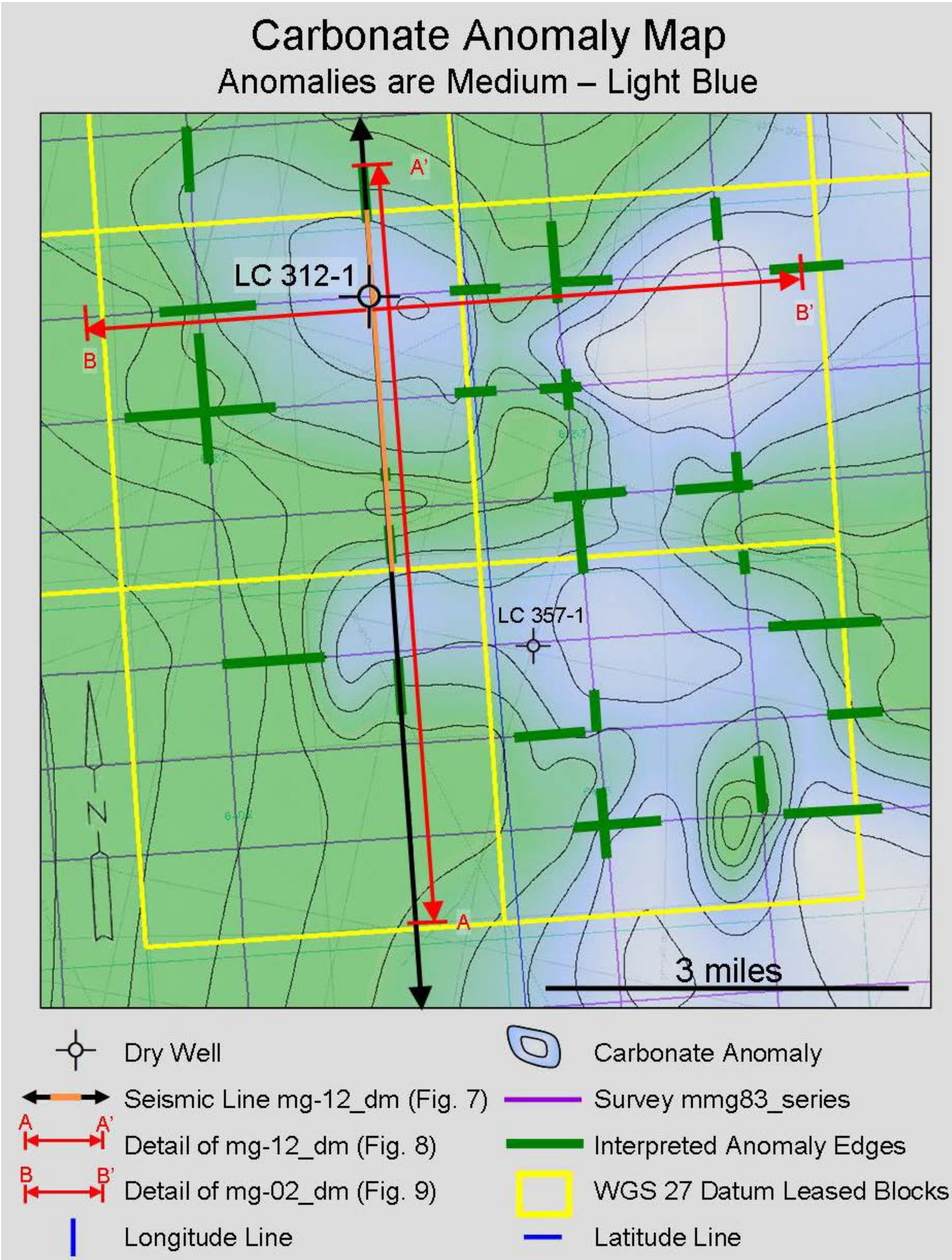

Figure 6. Carbonate anomaly map created by gridding interpreted anomaly edges. Note the locations of A – A', B – B', and seismic line mg-12_dm.

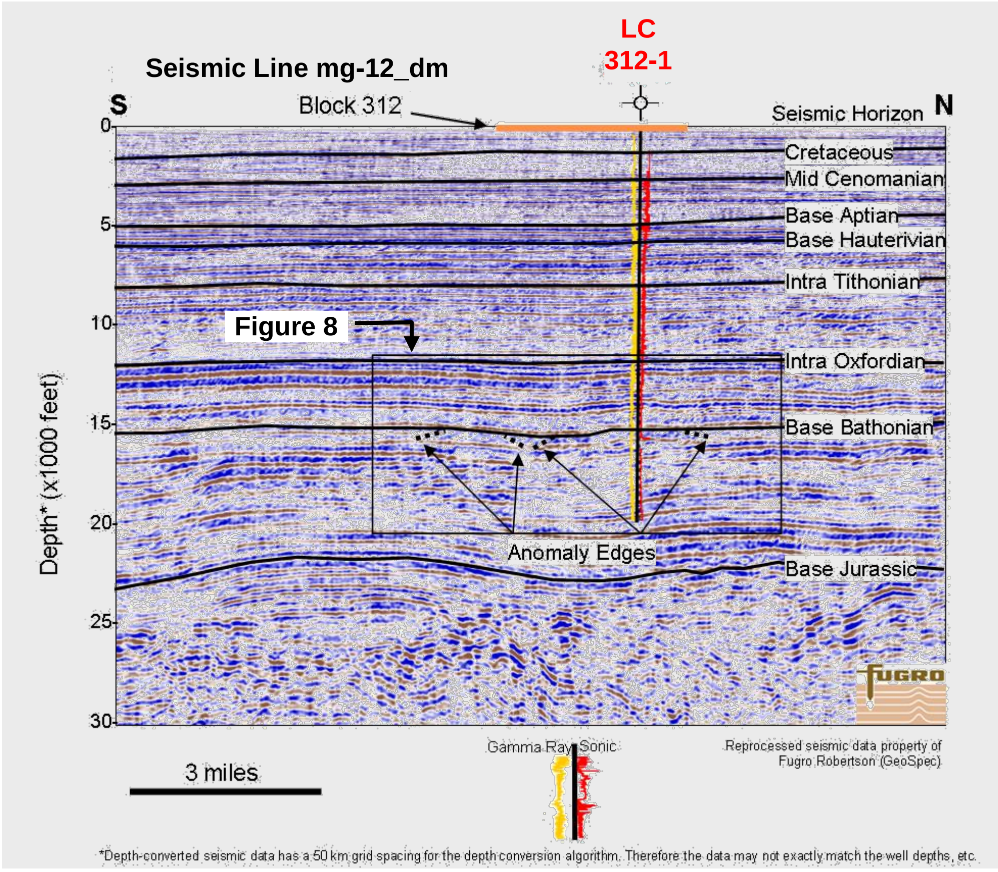

Figure 7. D-c, t-m seismic profile (south to north) with interpreted horizons (in black) and anomaly edges (black dashes). Detail of anomalies shown in Figure 8.

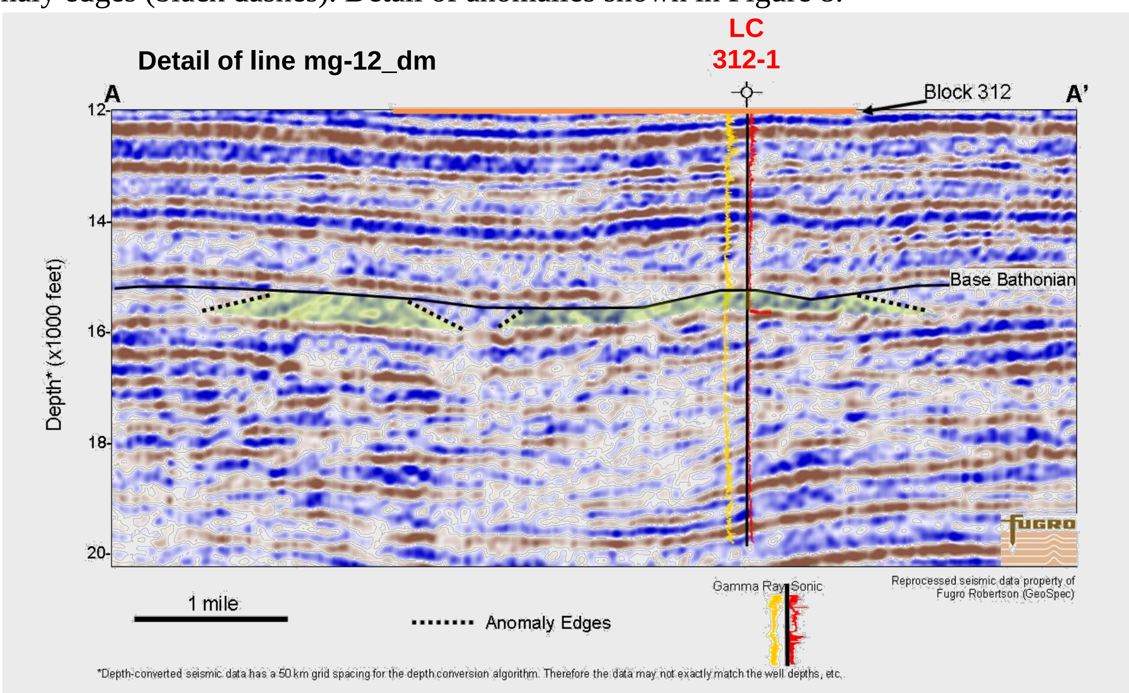

Figure 8. Detail of Figure 7 with the interpreted Base Bathonian horizon, anomaly edges (black dashes), and anomalies highlighted in green.

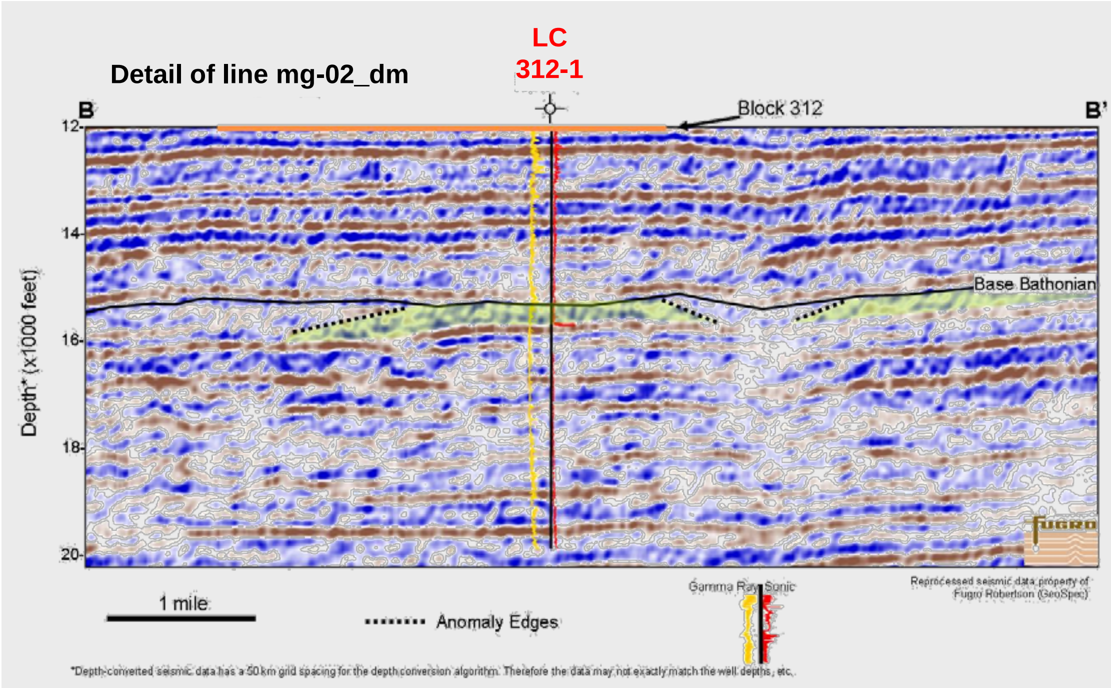

Figure 9. D-c, t-m seismic profile (west to east) through LC 312-1 showing detail of the interpreted anomalies (green highlight) and anomaly edges (black dash). The Base Bathonian horizon is represented by a black line.

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