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Lithology and X-ray mineralogy of the Shell 410-1 well, U.S. North Atlantic Outer Continental Shelf

by

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ABSTRACT

The Shell 410-1 well was drilled to a total depth of 4745 m relative to the Kelly Bushing in the downdip portion of the Georges Bank Basin. X-ray diffraction and petrographic analyses show that the well penetrated a section entirely composed of sedimentary rocks. Carbonates dominate the section below 3879 m and in the intervals 3848-3338 m, 3322-3018 m, and 1990-1722 m. Siliciclastics comprise most of the remaining section.

Calcite is the dominant cement throught the section; chert, siderite, hematite, dolomite, and phosphate cements are locally important. Glauconite is present above 3094 m and common above 1311 m. Anhydrite is sporatically common below 3300 m; phosphorite is found above 1212 m.

INTRODUCTION

The Shell Oil Company Lydonia Canyon Block 410-1 well was drilled in the Georges Bank Basin on the U.S. Outer Continental Shelf (OCS) between August 10, 1981 and March 31, 1982. The wellsite, which is located at latitude 40°34.387'N and longitude 67°12.531'W in 136 m of water, is approximately 250 km southeast of Nantucket, Massachusetts (Fig. 1). Drilling operations continued to a total depth of 4,745 m (15,568 ft) relative to the Kelly Bushing (RKB), for a total penetration depth of 4587 m below the seafloor. The well, which was plugged and abandoned after testing, has been classified as a dry hole. Although no significant source or reservoir rocks were encountered in the Shell 410-1 well, the lithological descriptions and X-ray diffraction data presented here contribute to our knowledge and understanding of the geological framework of the U.S. Atlantic margin.

All depth references in this report are based on depths relative to the Kelly Bushing (RKB). The distance below the sediment/water interface for any given sample may be calculated by subtracting 158 m (the sum of the 136 m water depth and the 22 m distance between sea level and the Kelly Bushing) from the depth RKB.

METHODS

The drill cutting samples were hand-picked to separate sufficient amounts of representative lithologies for description and analysis. Subsamples were subsequently washed, sonified, and rewashed in the laboratory to prevent contamination by drilling fluids. X-ray powder diffraction analyses were performed on 27 of the cutting samples from 3 to 30 m intervals at 26 levels in the well. Because the strata above 238 m were drilled without sampling, no lithological descriptions or X-ray diffraction analyses were performed on this interval.

A split from each sample was mounted and X-rayed as a randomly oriented powder. Semiquantitative estimates of the mineral abundances determined from the randomly oriented aggregate mounts

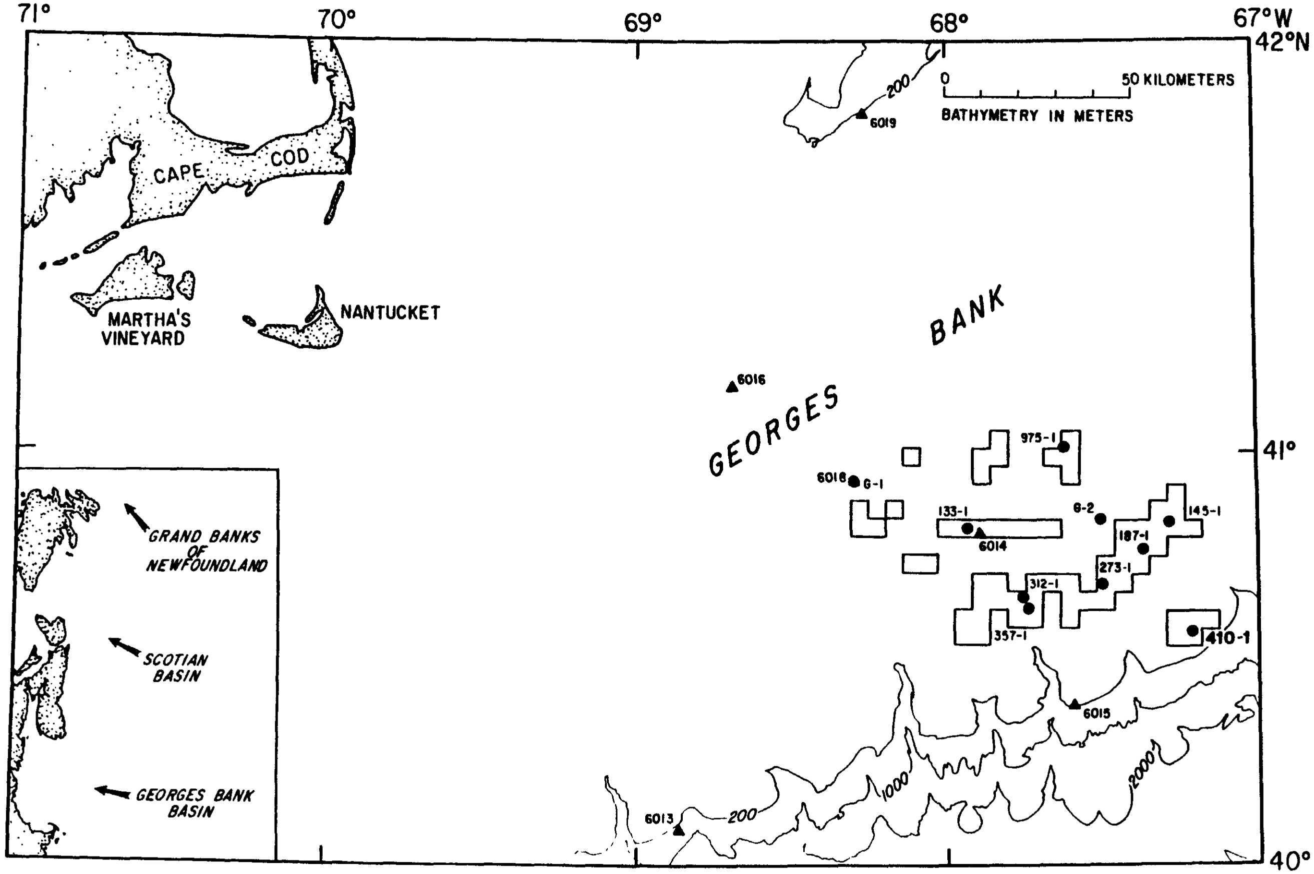

Figure 1. Map showing the location of the Shell 410-1 well in the Georges Bank Basin, north Atlantic Outer Continental Shelf. The distribution of the other drilled wells and the boundaries of the blocks leased during Sale 42 are also plotted on the map. Inset shows the location of the Georges Bank Basin, Scotian Basin, and Grand Banks. Dots indicate commercial exploratory and Continental Offshore Stratigraphic Test (COST) wells; triangles are USGS Atlantic Margin Coring Project wells (Hathaway and others, 1979).

were made bycomparing the sample diffraction peak areas and intensities with the areas and intensities recorded from a collection of external standards. The clay fraction (<2 μm) from each sample was separated by centrifuge and mounted as an oriented aggregate on a glass slide by a filter-membrane peel technique (Pollastro, 1982). Each oriented clay mineral sample was subjected to four treatments to determine which clay minerals were present: air-drying, glycolation with ethylene glycol, heating to 400 ^{o}C, and heating to 550 ^{o}C. Clay mineral abundances were estimated by a method described by Biscaye (1965) and the data from the randomly oriented and oriented aggregate mounts were combined. The semiquantitative estimates are reported in relative weight percentages of crystalline material and are generally considered to be accurate to within 10 percent of their actual values; however, even if due only to rounding errors, the lower values (<10 percent) may vary considerably more than this.

A split was taken from each sample and mounted in Piccolite (N=1.52) as a smear slide. These slides were used to check the semiquantitative diffraction results, to generate textural descriptions, to correct the data for layered silicates occurring in the silt fraction, to detect amorphous phases or those occurring in trace amounts, and to examine the biogenic debris.

The electric and geophysical logs, smear slides, X-ray diffraction patterns, and drill cuttings for the Shell 410-1 well are on file at the USGS office in Woods Hole, MA.

LITHOLOGY

The stratigraphic column penetrated by the Shell 410-1 well can be readily divided into ten major lithologic units (Table 1). These units correspond to formations that have been previously described in the Scotian (McIver, 1972; Jansa and Wade, 1975; Wade and McLean, 1990) and Georges Bank Basins (Poppe and others, 1992a,b; Poppe and Poag, 1993a,b).

Below 3879 m (Unit 1)

This interval is composed mainly of light-medium gray and brown dolomite and limestone. The dolomite, which contains scattered traces of visible porosity, is medium to coarse grained, commonly sucrosic and locally anhydritic. The limestone is mostly micritic, but locally pelloidal, oolitic, and dolomitic. The abundance of limestone increases upward in this portion of the section. Interbedded with these carbonates and concentrated below 4633 m are gray to pinkish gray, fine-grained, silica-cemented quartz sandstones. However, below 3879, siliciclastics make up only about 10% of the section.

3879-3848 m (Unit 2)

This interval is composed largely of thin, non- to slightly calcareous, greenish gray, gray, and brown shales, fine-grained

Table 1. Groupings of Mesozoic rock types encountered in the Shell 410-1 well. The values are presented in relative percent by volume.

DEPTH INTERVAL METERS	STRATIGRAPHIC EQUIVALENT	PERCENT SANDSTONE	PERCENT SHALE AND SILTSTONE	PERCENT LIMESTONE	PERCENT DOLOSTONE	PERCENT EVAPORITE	PERCENT COAL-LIGNITE	COMMENTS
326-238								Unconsolidated, Unit 10
442-326								Unconsolidated, Unit 9
887-442	Dawson Canyon Formation	17	82	1				Lithologic unit 8
899-887	Logan Canyon Formation	57	43					Lithologic Unit 7
939-899	Naskapi Shale Formation	22	77	Trace				Lithologic unit 7
939-1722	Missisauga Formation	43	41	15	Trace		Trace	Lithologic unit 6
1990-3018	Mic Mac-Mohawk Formations	2	57	40			Trace	Lithologic unit 4
	Abenaki Formation							
	Bacarro Limestone Member							
1722-1990	Upper Tongue	Trace	9	90				Lithologic unit 5
3018-3330	Lower Tongue	1	5	93		1		Lithologic unit 3
3345-3330	Misaine Shale Member		26	70		4		Lithologic unit 3
3345-3848	Scatarie Limestone Member	Trace	5	92		2	Trace	Lithologic unit 3
3848-3879	Mohican Formation	8	24	68				Lithologic unit 2
3879-4745	Iroquois Formation	9	1	66	23	Trace	Trace	Lithologic unit 1

silica- and calcite-cemented quartz sandstones, and dolomitic limestones.

3848-3018 m (Unit 3)

This interval is dominated by light gray, medium gray, buff, and light brown limestones. The limestones are very hard, dense, micritic, and locally pelloidal (below 3695 m), anhydritic (3620-3482 m), oolitic (3437-3338 m 3178-3147 m), and marly (3688-3658 m, 3521-3063 m). Stylolitic seams are common; visible porosity is rare. Interbedded with the limestones are medium to dark gray moderately calcareous shales (especially between 3338-3322 m), siltstones, and rare fine-grained, well-sorted, calcite-cemented sandstones.

3018-1990 m (Unit 4)

This portion of the section is primarily composed of medium to dark gray, friable shales. The shales, which are locally pyritic and cut by calcite veining, occasionally grade into poorly sorted quartz siltstones. Interbedded with these mudstones are numerous white to gray limestones and a few quartz sandstones. The limestones, which have micritic and finely sucrosic cements, are commonly oolitic. The sandstones are fine-grained, poorly to moderately sorted, and tightly cemented by calcite. None of the lithologies in this interval have any visible porosity. Lignite fragments recovered near the base of this unit have a woody appearance and are probably allochthonous.

1990-1722 m (Unit 5)

These strata are composed mainly of white and light to medium gray limestones with micritic to fine-grained sucrosic textures. These carbonates are also locally oolitic, marly, and glauconite- and fossil-bearing. Interbedded with the limestones are medium gray, soft-friable shales and dark gray calcareous siltstones. The shales are generally calcareous, and, locally, silty and pyrite-bearing.

1722-939 m (Unit 6)

This interval is composed primarily sandstone with lesser amounts of shale and limestone. The sandstones, which are concentrated toward the lower portion of this interval and fine upward, are fine- to coarse grained, poorly sorted, subangular to subrounded, and variably cemented with calcite. Light gray, medium gray, and green, calcareous, consolidated shales and sticky clays are more common toward the upper part of the interval. Both the sandstones and finer-grained lithologies are locally pyritic, glauconitic, and fossiliferous. White, tan, and gray, lime wackestones occur between these sands and muds (1366-1225 m). The limestones, which are locally oolitic, marly, fossiliferous, and dolomitic, contain traces of glauconite and quartz sand. Sparse fragments of lignite present throughout this interval probably represent allochthonous woody debris.

939-887 m (Unit 7)

These sediments are predominantly sticky, semiconsolidated, calcareous clays. Fine-grained quartz sand, glauconite, microfossils, and shell fragments are locally abundant.

887-442 m (Unit 8)

The sediments in this interval are dominated by medium to dark gray, sticky, semiconsolidated muds. These muds are generally non- to slightly calcareous, except in the intervals between 838-785 m and 732-701 m where carbonate content increases. Zones of abundant marine fossils, glauconite, and phosphate are also present. The phosphate occurs primarily as sand- and gravel-sized pellets and as cement in conglomeratic aggregates. Two intervals composed primarily of phosphatic greensand and variably cemented by calcite occur between 533-518 m and 495-472 m. Elsewhere, scattered thin beds of poorly sorted, fine-grained quartz sand are present, but make up less than 5 percent of the interval.

442-326 m (Unit 9)

These sediments are primarily greenish gray, unconsolidated clays. These clays are very calcareous and contain abundant pyrite, foraminifera, and shell fragments, and traces of dolomite, chert, glauconite, and phosphate.

326-238 m (Unit 10)

Unconsolidated fine to coarse-grained, siliciclastic sands and gravels were recovered in the interval above 326 m. These sands are generally moderately sorted, subrounded to subangular, and contain abundant shell fragments, traces of glauconite, and scattered drill cuttings which consist of shale, sandstone, conglomerate, and chert.

X-RAY MINERALOGY

Layered silicates, which range in concentration from a trace to about 60 weight percent, are a major siliciclastic component of the sediments (Table 2). Except in the interval between 3002-2984 m where chlorite dominates, illite/mica is the more common layered silicate below 2594 m. Kaolinite, which usually forms by chemical weathering under nonalkaline conditions either in the source areas or at the site of deposition, is the most common layered silicate between 2533-1981 m. Chlorite is usually more common than kaolinite below 2850 m and above 436 m. Smectites are rare or absent below 3000 m, but are relatively common between 2600-1800 m. Although

Table 2. Estimated mineral modes, in relative weight percent, determined from X-ray powder diffraction and smear slides for drill cuttings from the Shell 410-1 well. SMC: smectites; CHL: chlorite; I-S: mixed layer illite-smectite; I/M: illite and/or mica; KAO: kaolinite; GLA: glauconite; QTZ: quartz; AMO: amorphous silica and disordered cristobalite; FLD: feldspar; CAL: calcite; D/A: dolomite/ankerite; SID: siderite; PYR: pyrite; HEM: hematite; GOE: goethite; ANH: anhydride; APA: apatite. A blank indicates that the mineral was not detected; T = trace (<1 percent).

DEPTH (M)	SMC	CHL	I-S	I/M	KAO	GLA	QTZ	AMO	FLD	CAL	D/A	SID	PYR	HEM	GOE	ANH	APA	ZEO	COMMENTS
427-436	T	5	3	4	3		17	61	6	T			T						CHERT
472-482	T	T	T	T	T	T	T	87		10			T						CHERT
472-482	T	T	T	T	T	25	3			3			4				63		GLAUCONITIC PHOSPHORITE
1069-1076	T	T	1	1	1	5	45		5	9	26	1	5						SANDSTONE
1204-1213	1	T	T	T	1	7	35		3	48	1	2	1						CALCITE-CEMENTED SANDSTONE
1295-1305				T	T		2			90	7		T						LIGHT GRAY LIMESTONE
1817-1890	6	T	T	2	1	T	3			85			1						LIGHT GRAY MICRITIC LIMESTONE
1981-1984	T	T	1	T	3	T	3		T	89	T		T						LIGHT GRAY MICRITIC LIMESTONE
2286-2317	2	7	5	10	18	T	16		2	27		2	10						GRAY SHALE
2512-2515	3	4	1	3	8	T	50		6	23		T	T					T	GRAY SANDSTONE
2530-2533	T	T	1	2	2	T	7		T	85	T		T						LIGHT GRAY LIMESTONE
2594-2600	9	7	4	21	12	T	25		7	5		2	7						DARK GRAY SHALE
2752-2755		T	T	2	T	T	6		T	89			T						GRAY PELLOIDAL LIMESTONE
2765-2768	1	9	6	33	10	T	26		5	2		3	4						DARK GRAY SHALE
2856-2859	T	8	8	32	7		26		5	9		2	2						DARK GRAY SHALE
2984-3002	T	4	T	2	T		59		4	26	2	T	T						CALCITE-CEMENTED SANDSTONE
3076-3094		T	T	1	T	T	5		T	88	T	T	T						DARK GRAY LIMESTONE
3170-3188				T			2		1	95	T		T						LIGHT GRAY OOLITIC LIMESTONE
3719-3722				T			T		T	90	3					3			LIGHT GRAY LIMESTONE
3731-3737		T	T	3	T		2		T	88	2		T			2			DARK GRAY LIMESTONE
3938-3941		T	T	T	T		2			67	3		T			26			DARK GRAY ANHYDRITIC LIMESTONE
4249-4252				T			T		T	98	T								LIGHT GRAY LIMESTONE
4633-4636				T			1			26	76		T						LIGHT GRAY DOLOSTONE
4639-4642	T	1	3	45	1		23		3	8	4	T		10	T				REDDISH BROWN SILTSTONE
4642-4645		T	T	8	T		87		T		3								GRAY QUARTZARENITE
4651-4663			T	2	T		1			73	20		3						GRAY DOLOMITIC LIMESTONE
4734-4737		T	T	6	T		92		1										PINK QUARTZARENITE

minor amounts of mixed-layer illite-smectite occur throughout the section, it is never the most common clay mineral. No mixed-layer chlorite-smectite, palygorskite, or sepiolite were detected in any of the X-ray diffraction patterns; zeolites are present only in trace amounts.

Quartz, which ranges in grain size from gravel to fine silt, is present in every well sample. It occurs as both detrital grains and, below 4600 m, overgrowth cements. Potassium feldspar is locally more common than plagioclase below 4642 m and above 1100 m. Plagioclase is more common in the remainder of the well.

Calcite is clearly the most common cement above about 4600 m in the lithified siliciclastic sediments of the well. Below 4600 m, silica and hematite dominate. Dolomite (ankerite?) is common below 3850 m and in the interval between 1265-1257 m; siderite is locally common as a cement above 2860 m.

Traces of pyrite are common throughout much of the well, and some intervals, especially between 2591-2286 m and 1722-1069 m, contain zones that are quite pyritic. The pyrite, which is evidence for reducing interstitial paleoenvironments, occurs primarily in dark gray shales as framboidal spheres, but also occurs filling the tests of microfossils and encrusting lignitic fragments.

Glauconite occurs predominantly in its pelletal form and is concentrated above 1311 m in the well. This mineral, which is indicative of open marine depositional environments, is noticeably depleted or absent below 3094 m.

Anhydride is locally common in the limestones, dolostones, and reddish-brown siliciclastics below 3300 m in the section. This mineral usually forms under evaporitic conditions and suggests the presence of restricted marine or supratidal depositional environments.

Phosphorite, probably calcium fluorapatite, is found in the glauconitic sandstones and limestones above 1212 m in the well. The phosphorite, which typically occurs as course silt- and sand-sized pellets, was found in and around the interval between 482-472 m as subrounded nodular clasts as much as 2 mm in diameter. Petrographic examination of the pellets reveals aggregates of cryptocrystalline texture usually observed in marine phosphorites.

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