

MESOZOIC LITHOFACIES DEVELOPMENT AND ECONOMIC POTENTIAL OF
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Abstract

An interpretation of seismic facies and interval velocities from multichannel seismic reflection and refraction profiles collected over Georges Bank suggests the presence of a Jurassic-Early Cretaceous reef/carbonate bank underlying the outer continental shelf-upper continental slope off southern New England. North of this "reef-ridge" is the Georges Bank basin, which contains Jurassic platform carbonates overlain by Late Jurassic-Cenozoic clastics. Continuing progradation of these clastics resulted in the cessation of any reef growth in the earliest Late Cretaceous. Despite multiple dry holes on the adjacent Scotian Shelf, the oil and gas potential of the New England margin is high along both flanks of the buried Mesozoic carbonate buildup. Another promising drilling target is along the seaward side of the Yarmouth arch, a basement horst extending from Northeast Channel southwestward across Georges Bank to the continental slope.

INTRODUCTION

In spite of the development of plate tectonics over the past 20 years, the exact nature of the transitions between continental and oceanic crust remains unknown. Passive or "Atlantic-type" (Mitchell and Reading 1969, p. 631) continental margins overlie the continent-ocean transition when it occurs aseismically within a lithospheric plate. The juxtaposition of very different crustal types makes these margins sites of large vertical displacements and complex structures. Enormous accumulations of sediments also occur.

Recently, advanced geophysical techniques like multichannel seismic reflection profiling have allowed the deep structure and stratigraphy of passive margins to be examined in detail for the first time. Intensive investigations of passive margins are essential, not only for an understanding of their geologic evolution, but in order to make accurate assessments of their considerable economic potential.

PROCEDURE

In 1975 the Woods Hole Oceanographic Institution conducted an investigation of Georges Bank, part of the passive continental margin off eastern North America. Multichannel seismic reflection profiles were collected using a pneumatic sound source consisting of 4 air guns (300, 120, 80, and 40 in³) and a 1.2 km-long, 6-channel receiving array (Austin, 1978). Refraction profiles were also run using expendable sonobuoys in order to gather additional sediment and basement velocity information (fig. 1). By tying these data to multichannel seismic reflection profiles obtained over Georges Bank by the U.S. Geological Survey (fig. 1) and to the Shell Mohawk B-93 exploratory well drilled on the adjacent Scotian Shelf (fig. 1), we identified, dated, and mapped the major acoustic horizons in the Georges Bank basin (Maher, 1965; Austin et al, 1980).

DISCUSSION OF RESULTS

As shown by the cross sections (see fig. 2 and inset, fig. 3), the Georges Bank basin sedimentary section can be subdivided into two parts: a "rift" sequence restricted to grabens entrained within presumed Paleozoic and older rocks, and a "drift" sequence overlying the graben structures and thickening toward the outer shelf. The rifted crustal terrain is interpreted as the result of decoupling of Africa and North America during the latest Triassic-earliest Jurassic. Two major graben complexes are separated by the Yarmouth arch (Schultz and Grover, 1974; fig. 2), a horst extending from Northeast Channel southwest across Georges Bank to the vicinity of the continental slope. A surface (identified as reflector "K" (see Line 21/22, fig. 3) truncating the faulted blocks and associated graben-fill is here identified as a "breakup" unconformity (Falvey, 1974) carved at the time of continental separation (estimated now to be approximately 195-190 my B.P.; Austin et al, 1980). Following the formation of "K," margin subsidence in response to cooling (Sleep, 1971; Keen, 1979) initiated deposition of the "drift" sequence. That deposition continues today, as the North Atlantic widens in response to seafloor spreading.

Lithofacies Development

We calculated actual sediment thicknesses in the "drift" sequence by using interval velocities derived during processing of the reflection and refraction data. The Georges Bank basin may contain more than 13 km of sediment beneath the outer shelf and seaward of the Yarmouth arch (Line 21/22, fig. 3; Austin et al, 1980). These sediments are relatively undeformed and are acoustically similar to strata which have been extensively surveyed and sampled beneath the Scotian Shelf (McIver, 1972; Jansa and Wade, 1975; Given, 1977; Keen, 1979). By using Canadian seismic data and drilling results as a guide, we attempted a general prediction of the lithologies characterizing the Georges Bank basin. Figures 3-6 illustrate our interpretation of the Jurassic-Cretaceous lithofacies development of the New England passive margin.

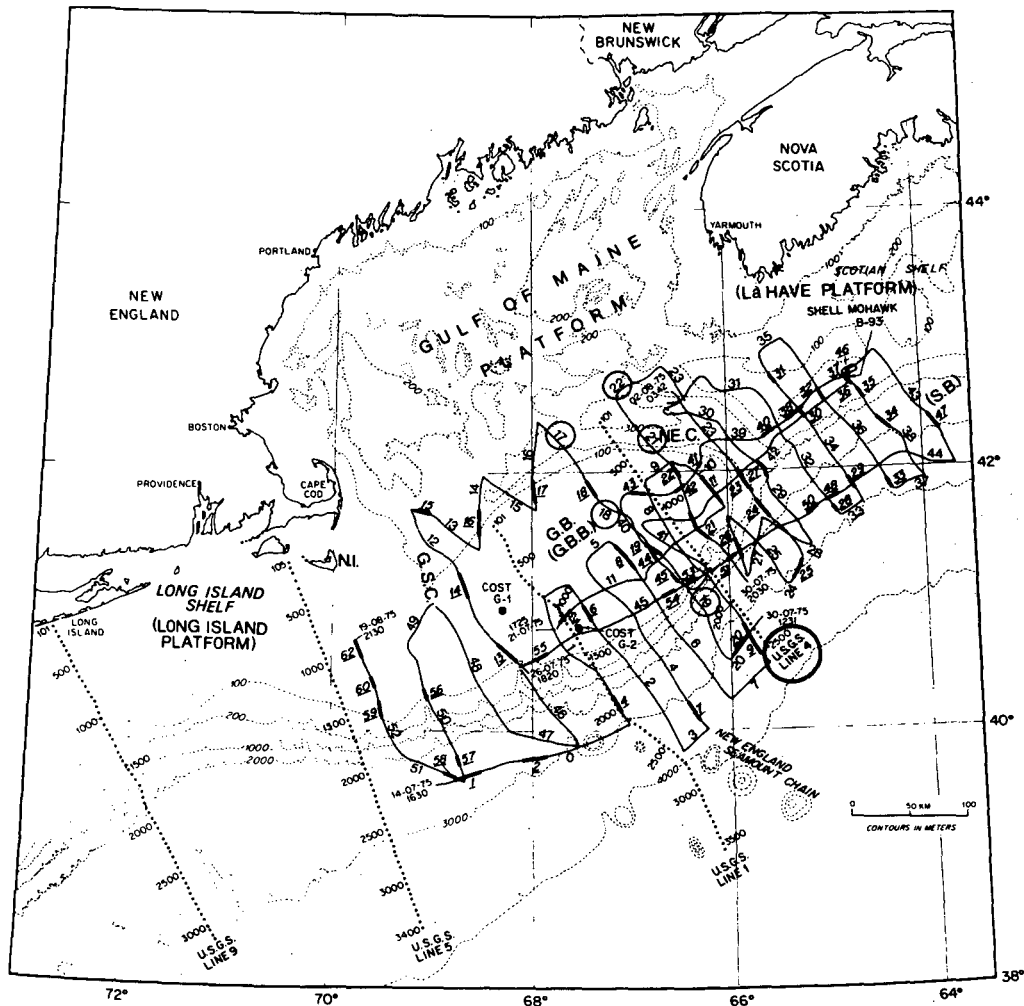


Figure 1. Geophysical data used during this investigation of the passive continental margin off southern New England. Solid lines: Woods Hole Oceanographic Institution seismic reflection profiles (6-channel on the continental shelf (inside the 200-m isobath), single-channel on the continental slope and rise. Dotted lines: U.S. Geological Survey multichannel seismic reflection profiles.

① : Profiles pictured on figures 2-6.

Short heavy line segments: Woods Hole Oceanographic Institution sonobuoy (seismic refraction) profiles (41: sonobuoy identification number).

N.I. : Nantucket Island

G.B. : Georges Bank

NE.C. : Northeast Channel

G.S.C. : Great South Channel

G.B.B. : Georges Bank basin (Maher, 1965).

S.B. : Scotian basin (Jansa and Wade, 1975).

The first marine incursion onto the Scotian Shelf following the separation of Africa and North America took place during the Early Jurassic. Evaporites were deposited. Subsequent plastic flow of these sediments has produced the diapiric ridge beneath the lower continental slope-upper continental rise off Nova Scotia (Jansa and Wade, 1975; figs. 3-6). Beneath Georges Bank seismic facies analysis (Mitchum et al, 1977) and interval velocity information indicate that Early Jurassic deposition was dominated by dolomites and limestones flanking a "high" situated beneath what is now the outer shelf-upper slope (fig. 3). Evaporites may be included with these predominantly flat-lying carbonates, but the only diapiric structure that we observed was located beneath Northeast Channel (fig. 1). Early researchers interpreted the topographic feature under the outer part of Georges Bank as a crustal structure (Drake et al,

1959; and others), but modeling of regional magnetic anomalies (Klitgord and Behrendt, 1979) indicates that real basement must be 6-7 km below the present crest of the high. The recent recovery of Early Cretaceous reefal limestone from the continental slope south of Georges Bank by the submersible DSRV *Alvin* (Ryan et al, 1978; figs. 2 and 5) suggests that at least part of the upper ridge is a reef complex. A reef/carbonate platform may have bordered much of the east coast during the Jurassic (Oil and Gas Jour., 1979, no. 37, p. 98).

During the Late Jurassic, clastics began to prograde across the Scotian Shelf (Given, 1977) and Georges Bank (fig. 4). This terrigenous debris cut through the "reef-ridge" at several points and must have caused a decrease in carbonate deposition all along the reef front by the end of the Jurassic.

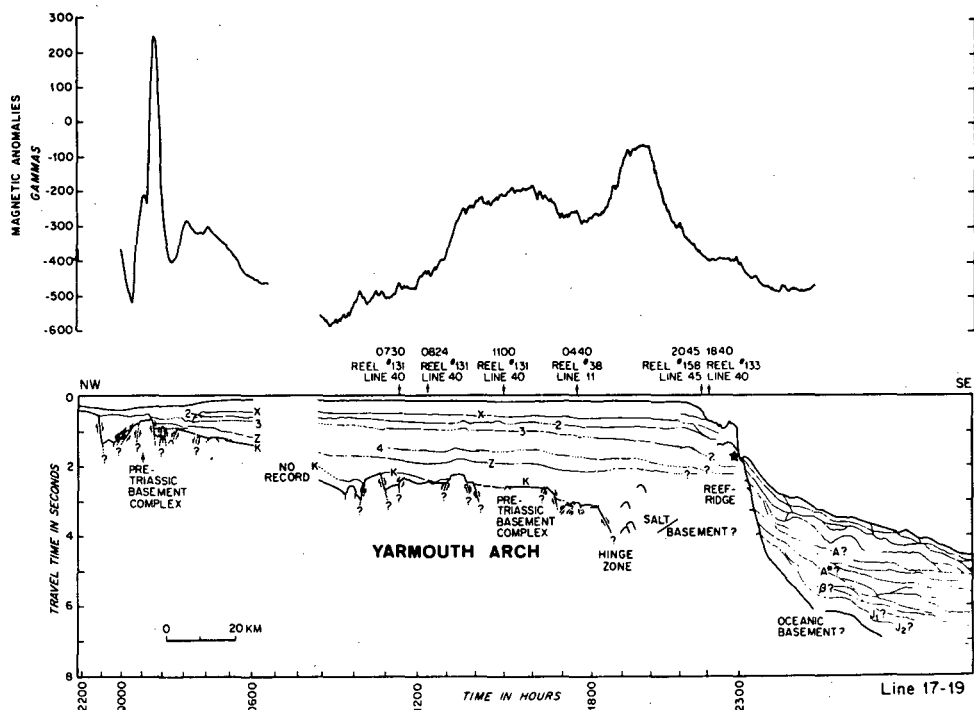
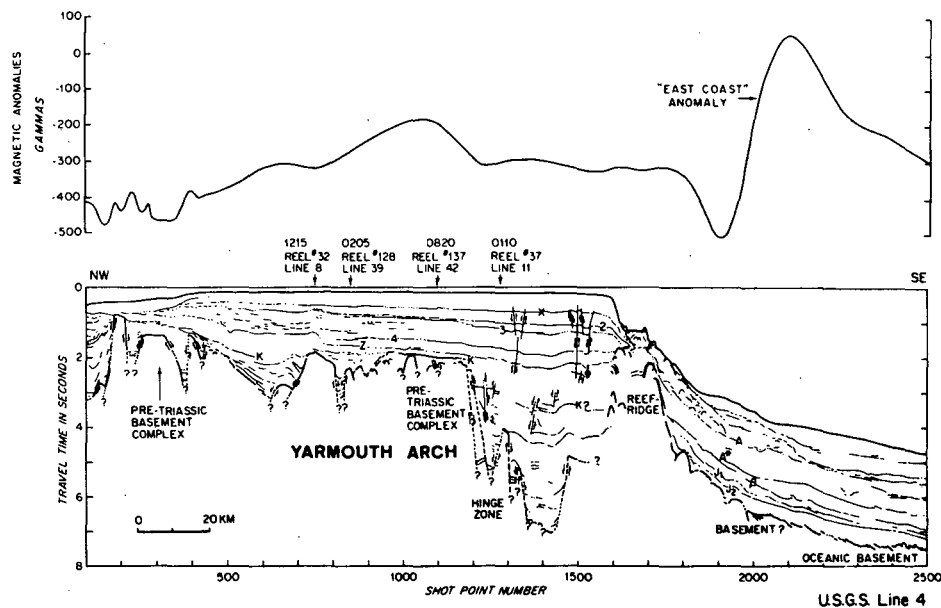


Figure 2. Interpretations of U.S.G.S. Line 4 (48-channel) and Line 17-19, the central part of Georges Bank. The "*" on the upper continental slope on 17-19 is the approximate location of the site from which Neocomian reefal limestone was collected by Ryan et al. (1978) in Heezen Canyon. See fig. 1 for locations of profiles.

Widespread deltaic conditions characterized the depositional regime of the east coast passive margin during the Early Cretaceous (Jansa and Wade, 1975; Given, 1977; fig. 5). Although patch reefs must have survived on the outer shelf-upper slope until at least the Neocomian (Ryan et al. 1978; see sample locations, fig. 5), the entire outer shelf carbonate province on Georges Bank was inundated by clastics by the beginning of the Late Cretaceous (fig. 6). Clastics appear to have dominated on Georges Bank since the Late Cretaceous (fig. 6).

The presently available geophysical results indicate that the buried Mesozoic reef/carbonate platform constitutes a good structural trap for oil and gas (see Line 21/22, fig. 3). Reflection profiles (figs. 2 and 3) suggest that the "reef-ridge" was eroded prior to burial (Austin et al, 1980). If this erosion was sub-aerial, which is implied by a mid-Cretaceous(?) calcareous sandstone recently sampled from the walls of Oceanographer Canyon (fig. 6) interpreted to have been deposited in a beach environment (Ryan et al, 1978), reservoir porosities and permeabilities could have developed. The weathered carbonates could be effectively sealed by Early Cretaceous and younger fluviodeltaic shales similar to those encountered in Canadian

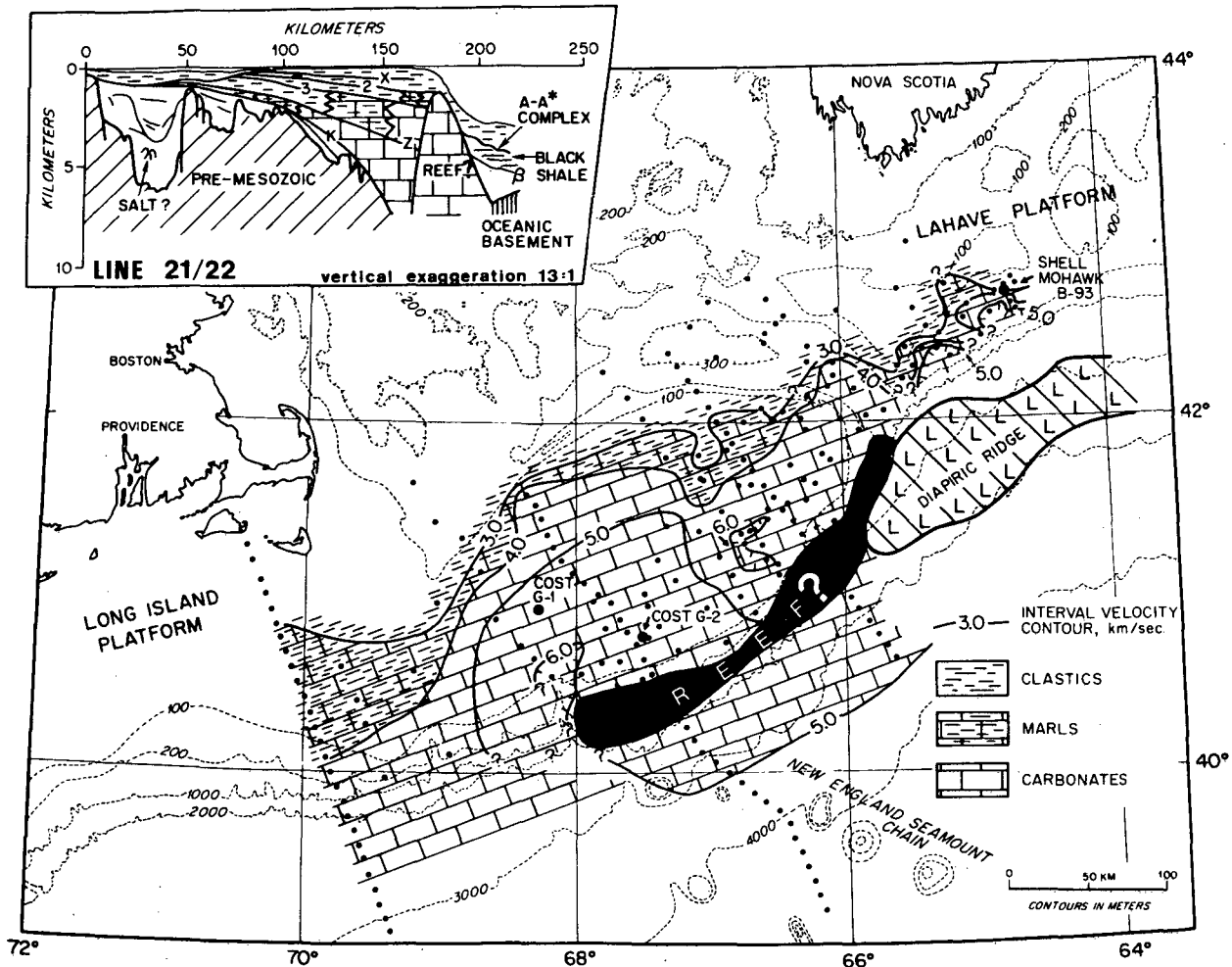


Figure 3. Early-Middle Jurassic lithofacies of the Georges Bank basin. Using Canadian exploration results as a guide along with seismic facies analysis, we attributed a carbonate lithology to all interval velocities >4.0 km/sec and a clastic (mixed sandstone - shale) lithology to velocities <3.0 km/sec. Velocities ranging between 3.0 and 4.0 km/sec were considered indicative of marls or a broad transition from clastics to carbonates. On this figure and figure 4 the regional extent of the "reef-ridge" is derived from interpretation of the reflection data and is only approximate. Inset: Simplified cross section of the eastern part of the Georges Bank basin along Line 21/22 (see fig. 1 for location). The estimated ages of major acoustic horizons are as follows: K: Triassic-Jurassic boundary; Z: Bathonian; 3: Jurassic-Cretaceous boundary; 2: Cenomanian; X: Turonian to Campanian; Beta: Hauterivian to Barremian; A*-A: Maestrichtian to earliest Miocene (Austin et al, 1980).

exploratory wells. (Givén, 1977).

must await confirmation by exploratory drilling.

CONCLUSIONS

Significant accumulations of hydrocarbons have not as yet been found on the Scotian Shelf, but more exploration needs to be carried out. If oil and gas have been trapped along either the flanks of the Georges Bank reef/carbonate platform or the seaward flank of the Yarmouth arch (see fig. 2), they are accessible with present drilling technology. Production on the continental slope (in water depths from 200-2000 m) should soon become economic as the cost of importing foreign petroleum continues to rise.

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The question of the availability and maturity of source rocks associated with the structural traps remains unanswered. Our data indicate that more than 80 percent of the Georges Bank basin is filled with Jurassic carbonates (Austin et al, 1980). The organic carbon content of these sediments is probably 1-3 percent, based upon wells drilled into similar Jurassic sections south of Nova Scotia (Purcell et al, 1979). Unfortunately, the top of the Jurassic is only 1-2 km beneath the present surface of Georges Bank, implying that at least the upper part of the Jurassic column is thermally immature (Dow, 1978). It is possible that Early Cretaceous black shales now presumed to underlie the upper continental rise (Tucholke and Mountain, 1979; see Line 21/22, fig. 2) could have provided a source for oil and gas which has since migrated upward through Jurassic reef/bank carbonates and/or Early Cretaceous deltaic sandstones (Mattick et al, 1978), but such a supposition

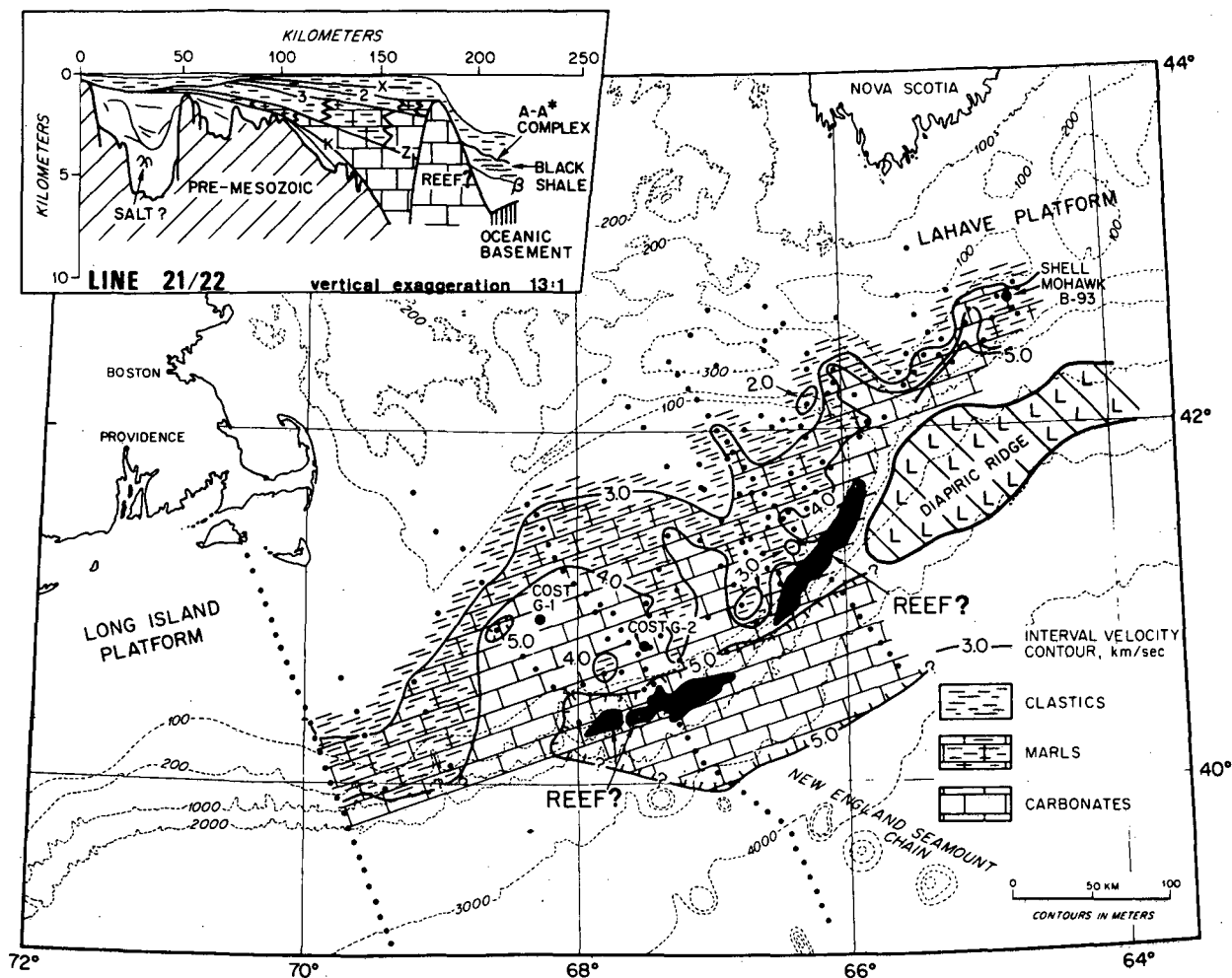


Figure 4. Late Jurassic lithofacies of the Georges Bank basin.

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REFERENCES

- AUSTIN, J.A., Jr., 1978, Geology of the passive margin off New England: Woods Hole Ocean. Inst. Tech. Report No. 79-27, 201 p.
- _____, UCHUPI, Elazar, SHAUGHNESSY, D.R. III, and BALLARD, R.D., 1980, Geology of the New England passive margin: Am. Assoc. Petrol. Geologists Bull. v. 64, p. 501-526.
- DOW, W.G., 1978, Petroleum source beds on continental slopes and rises: Am. Assoc. Petrol. Geologists Bull., v.62, p. 1584-1606.
- DRAKE, C.L., EWING, Maurice, and SUTTON, G.H. 1959, Continental margins and geosynclines: the east coast of North America, north of Cape Hatteras, in *Physics and Chemistry of the Earth*: London, Pergamon Press, v.3, p.110-198.
- FALVEY, D.A., 1974, The development of continental margins in plate tectonic theory: The Australian Petroleum Exploration Assoc. Jour., v.14, p. 95-106.
- GIVEN, M.M., 1977, Mesozoic and Early Cenozoic geology of offshore Nova Scotia: Bull. Canadian Petroleum Geology, v. 25, p.63-91.
- JANSA, L.F., and WADE, J.A., 1975, Geology of the continental margin off Nova Scotia and Newfoundland, in *Offshore geology of eastern Canada*, v.2, Regional Geology: Geol. Survey of Canada Paper 74-30, p. 51-105.
- KEEN, C.E., 1979, Thermal history and subsidence of rifted continental margins--evidence from wells on the Nova Scotian and Labrador shelves: Canadian Jour. Earth Sci., v.16, p.505-522.
- KLITGORD, K.D., and BEHRENDT, J.C., 1979, Basin structure of the U.S. Atlantic margin, in *Geological and geophysical investigations of continental margins*: Am. Assoc. Petrol. Geologists Memoir 29, p.85-112.
- MAHER, J.C., 1965, Correlations of subsurface Mesozoic and Cenozoic rocks along the Atlantic coast: Am. Assoc. Petrol. Geologists Cross Section Pub. 3, 18 p.

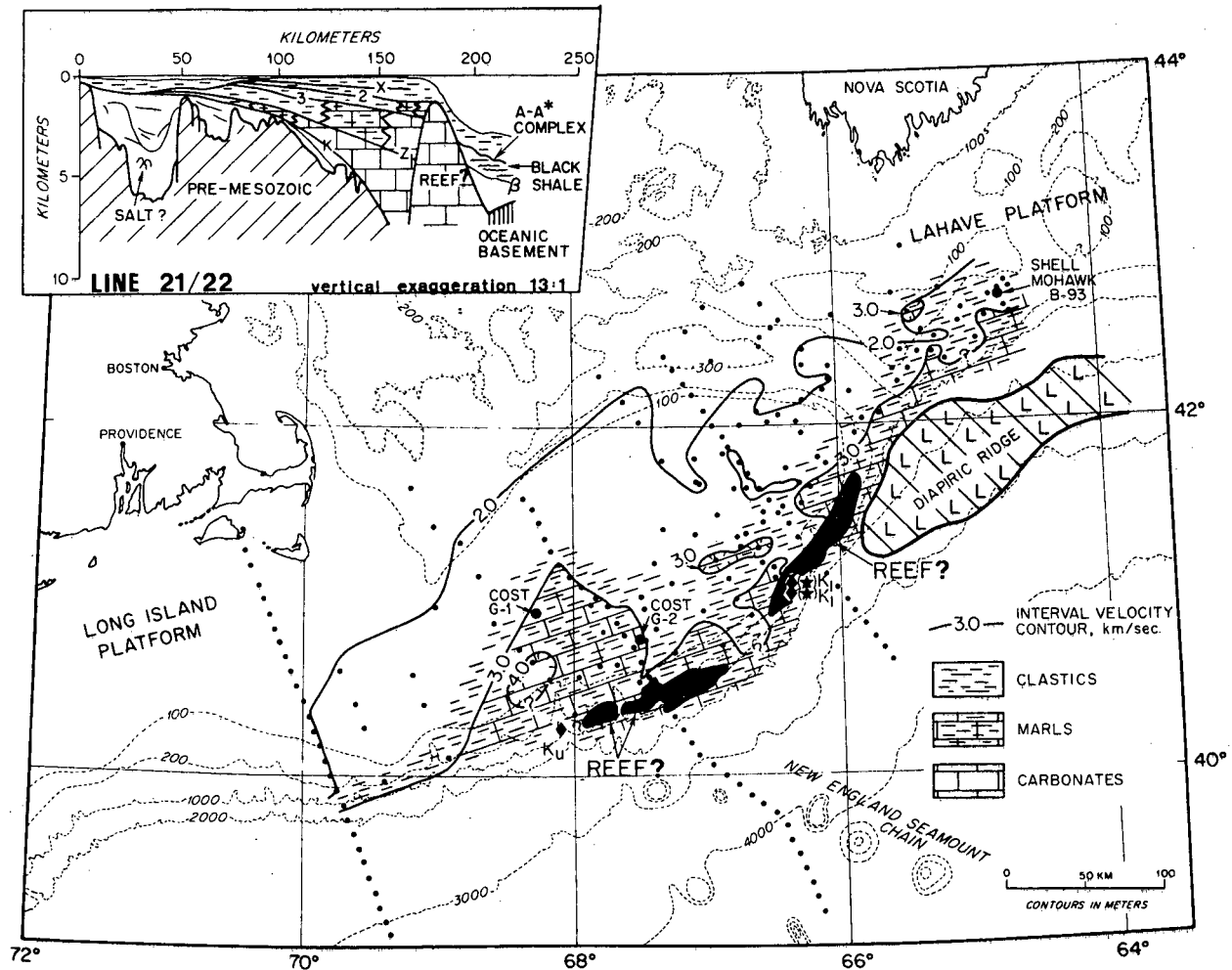


Figure 5. Early Cretaceous lithofacies of the Georges Bank basin. During this time, the "reef-ridge" was very patchy; thus it cannot be traced seismically. Therefore, for schematic purposes it is shown here as it appeared on Figure 4. On this figure and Figure 6, the location, age and lithology of samples recovered by various means from the continental slope south of Georges Bank are shown.

- MATTICK, R.E., GIRARD, O.W. Jr., SCHOLLE, P.A., and GROW, J.A., 1978, Petroleum potential of U.S. Atlantic slope, rise, and abyssal plain: *Am. Assoc. Petrol. Geologists Bull.*, v.62, p. 592-608.
- McIVER, N.L., 1972, Cenozoic and Mesozoic stratigraphy of the Nova Scotia Shelf: *Canadian Jour. Earth Sci.* v.9, p. 54-70.
- MITCHELL, A.H., and READING, H.G., 1969, Continental margins, geosynclines, and ocean floor spreading: *Jour. Geology*, v. 77, p.629-646.
- MITCHUM, R.M., VAIL, P.R., and SANGREE, J.B., 1977, Seismic stratigraphy and global changes of sea level, part 6: Stratigraphic interpretation of seismic reflection patterns in depositional sequences, in *Seismic stratigraphy--applications to hydrocarbon exploration*: *Am. Assoc. Petrol. Geologists Memoir* 26, p.117-133.
- OIL and GAS JOUR., 1979, Jurassic reef trend mapped off East U.S.: No. 37, p. 98-99.
- PURCELL, L.P., RASHID, M.A., and HARDY, I.A., 1979, Geochemical characteristics of sedimentary rocks in Scotian basin: *Am. Assoc. Petrol. Geologists Bull.*, v. 63, p. 87-105.
- RYAN, W.B.F., CITA, M.B., MILLER, E.L., HANSELMAN, D., NESTERHOFF, W.D., HECKER, B., and NIBBELINK, M., 1978, Bedrock geology in New England submarine canyons: *Oceanologica Acta.*, v.1, p.233-254.
- SCHULTZ, L.K., and GROVER, R.L., 1974, Geology of Georges Bank basin: *Am. Assoc. Petrol. Geologists Bull.* v.58, p. 1159-1168.

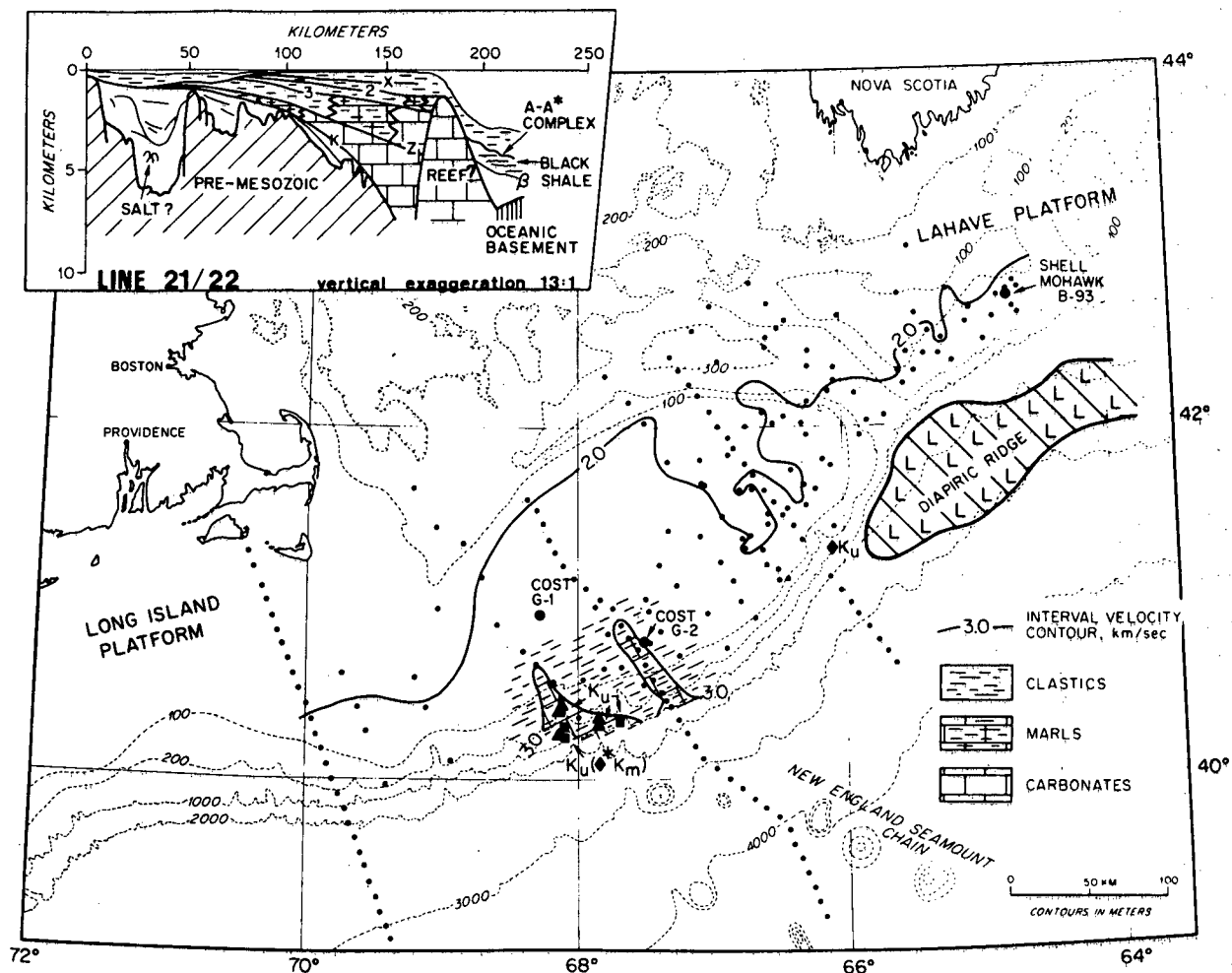


Figure 6. Late Cretaceous lithofacies of the Georges Bank basin.

SLEEP, N.H., 1971, Thermal effects of the formation of Atlantic continental margins by continental break-up: *Geophys. Jour. Royal Astr. Soc.*, v. 24, p. 325-350.
 TUCHOLKE, B.E., and MOUNTAIN, G.S., 1979, Seismic strati-

graphy, lithostratigraphy, and paleosedimentation patterns in the North American Basin, in *Deep-Sea Drilling Results in the Atlantic Ocean: Continental Margins and Paleoenvironment*: Am. Geophys. Union Maurice Ewing Series, v.3, p. 58-86.

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