GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA

PAPER 75-30

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Energy, Mines and Resources Canada
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601 Booth St., Ottawa, K1A 0E8

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Price - Canada: $3.50
Other Countries: $4.20

Catalogue No. M44-75-30

Price subject to change without notice

Information Canada
Ottawa
1976

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The Amoco-IOE Murre G-67 well, northeastern Grand Banks, penetrates over 10 000 feet of sediments. Seven rock units, 14 foraminiferal assemblages and 19 dinoflagellate, spore/pollen, or chitinozoan zones or assemblages have been recognized.

The well is notable for the presence near the bottom of marine Devonian rocks, 300 feet thick, overlain by 760 feet of undated red beds, followed by 6500 feet of marine Jurassic strata with abundant foraminifers, dinoflagellates, spores and pollen. The affinities of the Jurassic foraminiferal and dinoflagellate assemblages are strongly European. The Jurassic sequence may be one of the most complete in North America. All Jurassic standard stages from Hettangian to Kimmeridgian, and possibly also the Tithonian have been recognized.

Overlying the Jurassic, in ascending stratigraphic order, are Upper Albian, Cenomanian, Turonian, Lower Senonian, Eocene and Oligocene strata, with a combined thickness of over 2000 feet. The Turonian beds, rich in "Tethyan" foraminifers, probably are of outer neritic origin, the other post-Jurassic beds are shallow marine or marginal marine.

Rates of subsidence and sedimentation at the Murre G-67 site highest in the Jurassic and Turonian, did not exceed 6cm/1000 yr.

Résumé

Le puits Murre G-67, d'Amoco-IOE dans le nord-est des Grands bancs, traverse plus de 10 000 pieds de sédiments. On a pu y distinguer 7 unités pétrographiques, 14 faunes de foraminifères et 19 zones définies par des ensembles de dinoflagellés, de spores et pollens, ou de chitonidés.

Ce puits est remarquable par la présence, vers le fond, de 300 pieds de roches marines du Dévonien, recouvertes par 760 pieds de couches rouges dont on ne connaît pas l'âge, suivies de 6500 pieds de couches marines, d'âge jurassique, où abondent les foraminifères, dinoflagellés, spores et pollens. Les faunes de foraminifères et de dinoflagellés, du Jurassique, présentent de fortes affinités avec les faunes européennes correspondantes. Cette série jurassique est peut-être l'une des plus complètes de l'Amérique-du-Nord. Tous les étages classiques du Jurassique, de l'Hettangien au Kimmeridgien, et probablement aussi au Tithonien y ont été reconnus.

Recouvrant le Jurassique, on trouve, du plus ancien au plus récent, des couches de l'Albien supérieur, du Cénomanien, de Turonien, du Sénonien inférieur, de l'Eocène et de l'Oligocène, le tout ayant une épaisseur globale de plus de 2000 pieds. Les couches du Turonien, riches en foraminifères du type "Tethyan" proviennent probablement de la frange extérieure d'une zone néritique, les autres couches postérieures au Jurassique étant d'origine marine (eaux peu profondes ou marge continentale).

Les taux de subsidence et de sédimentation, à l'emplacement du puits Murre G-67, qui ont été maximaux au Jurassique et au Turonien, n'ont jamais dépassé 6cm/1000 ans.

STRATIGRAPHY OF THE AMOCO-IOE MURRE G-67 WELL, GRAND BANKS OF NEWFOUNDLAND

INTRODUCTION

This report describes the stratigraphy of the Amoco-IOE Murre G-67 well located on the northeastern Grand Banks, approximately 200 miles southeast of St. John's, Newfoundland at 46°06'20.4"N, 49°09'38.2"W (Fig. 1). The well was spudded July 14, 1971 in 212 feet of water and drilled to a total depth of 10 949 feet, with casing set at 477 feet, 835 feet, 2305 feet and 7782 feet. Murre was the second deep exploratory well (after Eider M-75) drilled on the Grand Banks by Amoco Canada Petroleum Company Ltd. and Imperial Oil Enterprises Ltd. The well was abandoned September 20, 1971 after hydrocarbon shows were reported at 9460 feet, 8950 feet and 8650 feet. The stratigraphy described here (Fig. 2) is a synthesis of lithostratigraphic studies (based on mechanical logs, and cuttings from 10 949 feet to 910 feet) by Jansa, thin section studies of the basement rocks by Harris, organic-walled microfossil studies (based on cuttings from 10 949 feet to 900 feet, 105 sidewall cores and one tricore) by Jenkins and Williams, and shelly microfossil studies (based on cuttings from 10 949 feet to 910 feet, and 49 sidewall cores) by Gradstein. The 33-inch tricore (in dolomite) from 8952 feet to 8949 feet was not available for the lithostratigraphic and shelly microfossil studies, and no conventional cores were taken in Murre. All footages were measured from the rotary table standing 98 feet above sea level and 310 feet above the sea floor.

This is the third in a series of papers describing the stratigraphy of Canadian east coast offshore wells. The two previously published reports deal with the stratigraphy of Shell Naskapi N-30 (Williams *et al.*, 1974) and Amoco-IOE Puffin B-90 (Jenkins *et al.*, 1974).

There are four main parts to this report: (1) Lithostratigraphy; (2) Biostratigraphy; (3) Depositional history; and (4) Subsidence and sedimentation.

Acknowledgments

We thank K. LaBorde, Robertson Research (North America) Ltd., Calgary, and J.A. Wade, Atlantic Geoscience Centre, Geological Survey of Canada, Dartmouth, for their constructive criticism of the typescript; Imperial Oil Ltd. for sidewall core material; and W. MacMillan for compiling Figure 2. We also thank G. Cook who drafted the figures, and Elaine McMullin for typing of the manuscript.

LITHOSTRATIGRAPHY

The lithostratigraphic succession in the vicinity of Murre G-67 is made up of seven units (Fig. 2). Three of these are formally designated formations having their type sections on the Scotian Shelf (McIver, 1972); three are unnamed sequences not readily referable to any

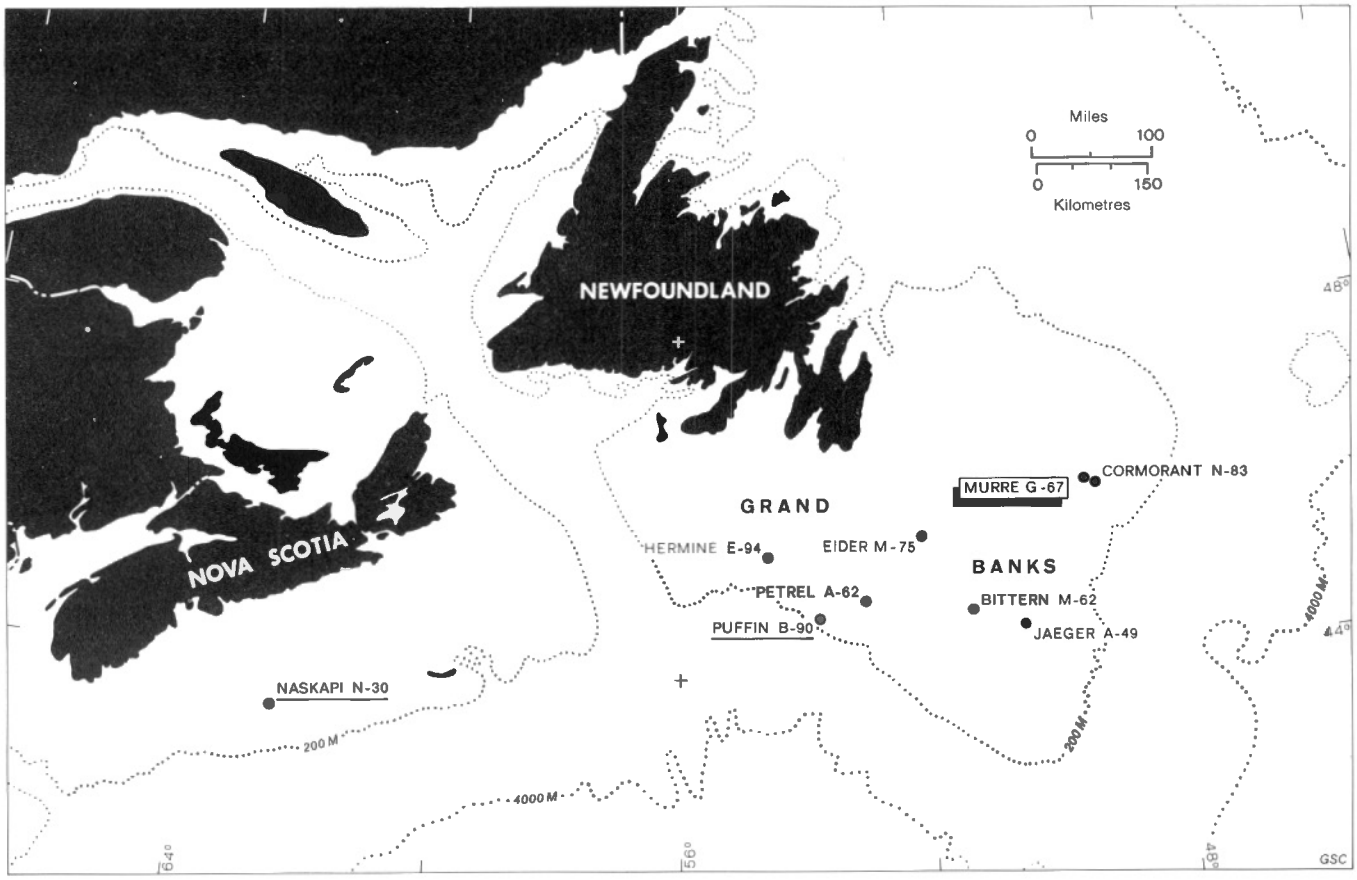

Figure 1. Index map.

rock units previously described from the Atlantic continental margin; and one, the Whale unit, is named informally and described here for the first time. In ascending stratigraphic order the succession is; unnamed metasediments, unnamed red beds (with basal conglomerate), the Iroquois Formation, the Whale unit, the "Mic Mac" Formation, an unnamed clastic sequence, and the Banquereau Formation. The succession has been described and interpreted from ditch cuttings, and from spontaneous potential, resistivity, gamma ray, sonic and dipmeter logs. Sidewall cores were not available for lithostratigraphic studies.

Unnamed metasedimentary rock (10 949 T.D. to 10 350 feet): The bottom 600 feet of strata in Murre G-67 are chlorite-grade metamorphic rocks that rest unconformably beneath an unmetamorphosed basal conglomerate at 10 350 feet. The dipmeter log indicates that these strata are gently inclined. At 10 620 feet, a change in the direction of dip (from mainly easterly below 10 620 feet to mainly northerly above) and an increase downwards in the degree of organic metamorphism indicates the presence of a fault or, less likely, an unconformity. Recognizable microfossils are restricted to the interval above this break.

The rocks consist of medium to light grey, silty slate with subordinate metasiltstone and metasandstone laminae and possibly in thin beds. In thin sections of the well cuttings, the slate is seen to consist of fine grained chlorite, muscovite, quartz, feldspar and carbonate. Silt- and sand-sized detrital grains are dispersed in varying amounts throughout much of the slate. Porphyroblasts of chlorite (pennine) are present but not abundant. Oriented chlorite and mica grains impart a weak foliation to the rocks. The foliation is developed oblique to sand and silt laminae that commonly occur rhythmically interlayered with the slate. The interlaminae contacts range from sharp to gradational. Examples of sandstone and siltstone without interlayered slate are present in the well cuttings also. Much of the metasandstone is poorly sorted and matrix-rich (mainly arkosic wacke), but some is moderately well sorted and matrix-poor (arkosic arenite). The principal framework components consist of quartz, chert, plagioclase, orthoclase and carbonate. The sandstone, siltstone and slate are cut by thin veins of quartz and carbonate. Finely disseminated pyrite is present in many of the cuttings.

These rocks contain acritarchs, chitinozoans and spores of the *Hystrichosporites-Sphaerochitina* assemblage and are of Middle Late Devonian age.

Unnamed red beds (10 350 to 9590 feet): An unnamed sequence of red beds 760 feet thick rests unconformably on the unnamed metamorphic rocks at 10 350 feet, and is in sharp contact with the overlying Iroquois Formation at 9590 feet. A ten-foot-thick layer of conglomerate at the base of the sequence contains pebbles of quartzose sandstone, orthoquartzite, chloritic quartzite and quartzose siltstone derived from older sedimentary and low grade metamorphic source rocks.

Above the basal conglomerate are 450 feet of monotonous dark reddish brown silty shales (green locally, where ferric oxide has been reduced to ferrous oxide), containing occasional thin argillaceous siltstone beds and scattered quartz grains with frosted surfaces. These strata are overlain by a thin dolomitized mollusc coquina, overlain, in turn, by 300 feet of moderately reddish brown, slightly silty, shales in which fine sand grains are widely dispersed. This upper division of the red bed sequence contains anhydrite, probably in nodules and veins, and becomes calcareous towards the top.

The red bed sequence contains no microfossils and consequently has not been dated paleontologically. However, red shale cuttings from 10 660 feet yielded a potassium-argon ($^{40}Ar/^{40}K$) radiometric date of 275 ± 10 million years (Amoco Canada, 1973), which in chronostratigraphic terms would be Late Pennsylvanian or Early Permian. The depth from which these cuttings were recovered is below the base of the unnamed red beds, but the sample is thought to represent cavings from this unit. The sample was handpicked, and this minimizes the likelihood that it may have been contaminated with material from the unnamed metasediments. The measured age could be interpreted as a minimum age limit for the shale, in view of a general tendency of shales to yield radiometric ages that post-date their time of deposition. Jansa and Wade (1975) suggest a Triassic age for the red beds sequence.

Iroquois Formation (9590 to 8454 feet): The Iroquois Formation, corresponding to the informal unit, the "Murre Carbonate" of Amoco Canada and Imperial Oil (1973), is 1136 feet thick and may be divided lithologically into three parts of almost equal thickness. The lower part (9590 to 9220 feet), consists of yellowish brown, occasionally anhydritic, microcrystalline dolomite, and occasional (rare) beds of dolomitized peloidal wackestone, oolitic grainstone and dark grey shale. The presence of several halite beds, two of them each about twenty feet thick, is interpreted from mechanical logs although no halite has been observed in the cuttings. Angular fine grained quartz sand is scattered throughout the dolomite, and quartz silt forms rare laminae. Vuggy, pin-point porosity and oil staining were observed. Styolites and scattered pyrite are common. Finely crystalline dolomite with beds of dolomitized peloidal micrite and rare laminae of dolomitized micritic intraclasts cemented by anhydrite occur at the base of the sequence.

The middle part of the Iroquois Formation (9220 to 8815 feet) is similar in composition to the lower part but lacks halite beds. It consists of finely crystalline dolomite with a minor amount of skeletal, peloidal, and rare oolitic limestone, all replaced by dolomite. Dolomite occasionally encloses sand-size quartz grains and voids filled with diagenetic silica. Finely crystalline dolomite occurs interbedded with medium crystalline dolomite having an intercrystalline, vuggy porosity. Fair to excellent porosity is developed in the interval 9220 to 8910 feet, in parts of which the dolomite is oil-stained. Anhydrite occurs in about 10 per cent of the

cuttings but is always separated from the carbonate, which suggests that it forms thin beds and/or nodules. Rare pieces of dark grey shale are present in the cuttings, and the presence of five shaly beds each less than 5 feet thick can be interpreted from the mechanical logs.

The upper part of the formation (8815 to 8454 feet) consists of light grey and pale brown micritic limestone interbedded with skeletal (rare foraminifers, fragmentary molluscs and echinoderms) and oolitic limestones and peloidal packstone. The latter is made up of peloidal grains and micritic intraclasts. The rims of skeletal grains and intraclasts are often blackened, possibly with iron monosulphide or manganese oxide. The oolites have a fibrous radial fabric and are cemented by bladed sparry calcite or, rarely, by chalcedony.

The Iroquois Formation contains spores of the *Heliosporites reissingeri* (9571 to 8781 feet) and *Cerebropollenites mesozoicus* (8766 to 8454 feet) assemblages. The lower and middle parts of the formation are dated Hettangian-Sinemurian, the upper part Pliensbachian. The lithostratigraphic boundary with the overlying unit is gradational.

Whale unit[1] (8454 to 3740 feet): The informally named Whale unit consists essentially of shale in the lower 1866 feet (shale member), interbedded limestone and shale in the middle 628 feet (limestone member) and shale with marlstone and limestone beds in the upper 2220 feet (shale-limestone member).

The lower shale member has at the base an approximately 100-foot-thick transitional zone composed of interbedded limestone, marlstone and shale. The limestone in the transition zone is an argillaceous glauconitic skeletal packstone and grades upwards into progressively less calcareous light grey marly shales. The overlying part of the member consists predominantly of medium dark grey, calcareous and silty shale which in places is slickensided. Thin beds of calcareous glauconitic siltstone cemented by ferroan sparry calcite, and beds of argillaceous micritic limestone are occasionally present. Echinoderms, gastropods, molluscs, coal partings and siderite nodules have been observed and some bioturbation is indicated by thin burrows filled with pyrite.

The middle limestone member (6588 to 5960 feet) consists of light grey to white limestone interbedded with light grey and light brownish grey calcareous shale. Between 6588 and 6236 feet, four limestone beds 35 to 133 feet thick alternate with beds of shale 5 to 50 feet thick. The shale at 6380 feet is reddish brown. The limestones are skeletal-peloidal grainstones and wackestones interbedded with oolitic and intraclast limestones. Skeletal grains frequently are micritized and the original fabric obliterated. Fossils recognized include ammonites, echinoderms, foraminifers, gastropods and solenoporoid algae.

The limestone above 6236 feet is made up of thin beds of intraclast-bioclast packstone, peloid-quartz sandy packstone and oolitic grainstone interbedded with beds of light grey calcareous silty mudstone, light grey siltstone and occasionally fine grained calcareous sandstone. Rare oolitic grains occur within the sandstone beds. They are finely veined with calcite, but little recrystallization has taken place. Ooids have nuclei of quartz grains, foraminifers and micrite enclosed by concentric lamellae of radial fibrous calcite, and are cemented together by sparry calcite. Dolomite and chalcedony cement are rare. The top of the limestone member, placed provisionally at 5960 feet, is marked by a breccia of reworked oolitic grainstone intraclasts in an argillaceous matrix. The boundary between the middle limestone member and the upper shale-limestone member is gradational and could be placed either at 6236 feet at the top of a massive limestone; or 5960 feet as selected in this paper, at the top of thin interbedded quartz-sandy limestone, siltstone and calcareous shale; or at 5790 feet, where the laterolog shows a marked reduction in the number of thin high resistivity (calcareous) beds. In Amoco Imperial A-1 Cormorant K-83, 9.8 miles to the southeast, the Whale unit is a shale without any limestone intercalations.

The upper shale-limestone member (5960 to 3740 feet) is a sequence of grey calcareous shales 2220 feet thick with thin marls and argillaceous limestone beds in the lower part (5960 to 5420 feet) and a few thicker limestone beds in the upper part (4680 to 3740 feet).

A transition zone (5960 to 5420 feet) between the limestone member and the overlying shale-limestone member is characterized by an upward increase of the shale-limestone ratio. In it occur calcareous mudstone and siltstone interbedded with quartz sandy and silty limestone beds up to ten feet thick consisting of algal oncolite-intraclast packstone and grainstone and wackestone, and one bed of oolitic limestone at 5850 feet, in which anhydrite and dolomite replace sparry calcite cement (possibly indicating a short period of emergence). An ammonite fragment was found at 5550 feet.

The sequence above 5420 feet is dominated by shales which contain thin coaly particles on bedding planes, rare siderite nodules of concretions and rare pyrite-filled burrows. Occasional beds of argillaceous medium grey siltstone and fine grained argillaceous and calcareous sandstone, up to a few feet thick, occur throughout the formation but are more common in the lower part of the transition zone (5960 to 5790 feet) and in beds at about 4000 feet transitional to the "Mic Mac" Formation. Quartz grains in the sandstones are well sorted, well rounded, and cemented by silica and calcite.

Between 4680 and 3740 feet, limestone beds interbedded in the sequence are up to 30 feet thick and consist of buff, quartz sandy skeletal peloidal packstone, skeletal peloidal wackestone, and oncolite-intraclast wackestone. They contain foraminifers, molluscs, bryozoans, and echinoderms. Oncolites consist of bioclasts and micritic nuclei coated by the algae *Girvanella*. Iron sulphide or manganese oxide rimming some of the bioclasts, may indicate that the grains were

[1] The Whale unit as used in this paper does not correspond to the Whale unit defined by Jansa and Wade (1975).

deposited initially in a reducing environment and subsequently reworked. Irregular surfaces coated by iron sulphide in the limestone at 4460 to 4420 feet resemble those found in hardgrounds or associated with surfaces that indicate prolonged periods of non-deposition.

The lower shale member of the Whale unit contains the *Involutina liassica* (8454 to 7840 feet), *Lenticulina d'orbignyi* (7800 to 6830 feet) foraminifer assemblages, and the *Cerebropollenites mesozoicus* (8454 to 7960 feet), *Nannoceratopsis gracilis* (7870 to 6450 feet) palynomorph assemblages. It is Pliensbachian, Toarcian and ?Bajocian age. The middle limestone member contains *Garantella* aff. *rudia* and *G. ornata* (6770 to 5960 feet) foraminifer assemblage and *Ctenidodinium pachydermum* (6355 to 5992 feet) dinoflagellate assemblage. It is of ?Toarcian and Bajocian age.

The lower part (5960 to 5730 feet) of the upper shale-limestone member contains the *Garantella ornata* (5960 to 5730 feet) and "*Globigerina*" *bathoniana* (5700 to 5260 feet) foraminifer assemblages and the *Gonyaulacysta filapicata* (5900 to 5270 feet) dinoflagellate-spore assemblage, which is similar to the German Bathonian assemblages described by Gocht (1970). It is dated Bathonian. The middle part of the member containing the *Reinholdella crebra* var. (5190 to 4419 feet) foraminifer assemblage and belonging to the *Valensiella vermiculata* (5260 to 4445 feet) dinoflagellate-spore Zone, is of Callovian age. The upper beds (4419 to 3740 feet) contain the *Epistomina mosquensis* assemblage (4419 to 4070 feet) and *G. cladophora* Zone (4058 to 3740 feet); they are Oxfordian and Kimmeridgian in age. The boundary with the overlying formation is gradational and has been placed at the first well defined sandstone bed on mechanical logs and cuttings.

"Mic Mac" Formation (3740 to 2975 feet): The "Mic Mac" Formation consists chiefly of sandstone beds 10 to 30 feet thick interbedded with thin mudstones and limestones. It lies unconformably beneath an unnamed clastic sequence. Contacts between the sandstone and mudstone/limestone beds are sharp. The sandstones are light grey to white, quartzose, fine to medium grained and friable. Quartz grains are well rounded and moderately to well sorted. Superficial oolites, oolites with quartz nuclei, quartz grains with micritic envelopes, and fragments of molluscs and coal are frequent constituents of the sandstones. Some sandstones have sparry calcite cement, others have micritic matrices.

The mudstone is light grey, calcareous and sometimes silty, and contains glauconite grains and fragments of molluscs and coal.

Limestone beds average 10 feet in thickness and predominate between 3470 and 3370 feet where they are interbedded with sandstone. The limestone typically is sandy and contains oolites with nuclei of quartz grains, peloidal grains, foraminifers and fragmentary molluscs. In one limestone, oolites are cemented by bladed isopachous and fibrous sparry calcite, indicating that cementation was early and took place in a submarine or phreatic zone. A mollusc coquina bed occurs in the upper part of the formation.

The "Mic Mac" Formation in Murre G-67 is similar to the transitional zone between the Mic Mac and Mississauga formations on the Scotian Shelf and provisionally is correlated to the Mic Mac Formation. The greater quantity of sandstone in Murre G-67 is consistent with the latter's location close to the late Jurassic paleoshoreline.

The lowermost beds of the formation contain the *Epistomina mosquensis* (3740 to 3445 feet) foraminifer assemblage and are referred to the dinoflagellate-spore Zone of *Gonyaulacysta cladophora* (3740 to 3650 feet). The remainder of the formation contains the *Leptolepidites psarosus* (3624 to 3114 feet) spore assemblage. The upper 470 feet contains no marine microfossils (foraminifers, dinoflagellates). The formation is of Kimmeridgian and possibly Tithonian age.

Unnamed clastic sequence (2975 to 2095 feet): This sequence is bounded at the bottom and top by regional unconformities. For descriptive purposes the sequence is separated into three parts. The oldest of these is a conglomerate-sandstone-siltstone-mudstone succession (2975 to 2750 feet) that is tentatively considered to be a highly condensed equivalent of the "Eider Unit" as described from other Grand Banks wells (Amoco Canada and Imperial Oil, 1973). Porous conglomerate in a bed 40 feet thick contains pebbles of white metaquartzite and orthoquartzite and tan dolomite in a reddish mudstone matrix. Less common constituents are chert, siderite concretions and coalified plant fragments. A thin bed of reddish mudstone overlies the conglomerate and is in turn overlain by light grey, interbedded sandstones, siltstones and calcareous silty mudstones. The sandstones are friable, fine grained and glauconitic. Quartz grains are moderately well sorted and cemented by sparry calcite, which in places is replaced by dolomite. Glauconite and phosphatic pellets form up to 15 per cent of the sandstone, and foraminifers, molluscs and ostracods are also present.

The siltstones are similar in composition to the sandstones.

The middle part (2750 to 2400 feet) of the unnamed clastic sequence comprises 350 feet of interbedded calcareous, silty mudstones and very fine grained glauconitic argillaceous siltstones overlain (at 2530 feet) by light grey calcareous mudstones. Foraminifers, molluscs and nannofossils occur throughout the sequence. The lithologies and age of these strata suggest that they are, at least in part, the nearshore equivalent of the Petrel Member as described by Jansa and Wade (1975).

A sandstone succession forms the upper part (2400 to 2095 feet) of the unnamed clastic sequence. It consists of fine grained sandstone interbedded with mudstone (below 2230 feet) and conglomeratic and coarse grained sandstone (above 2230 feet). The lower sandstone is light grey, friable. Some of the sandstones are cemented by sparry calcite or have a micritic matrix. Quartz grains are subangular and moderately sorted. Plagioclase and microcline form 10 per cent, and glauconite 3 per cent of the sandstone, whereas muscovite, biotite and chlorite are rare. The mudstone is brownish, greenish grey and light grey, calcareous and silty.

The sandstone above 2230 feet contains frosted, subangular, well-sorted quartz grains, molluscs and bryozoans. One shark's tooth bored by algae was observed. Quartz grains towards the top of the unnamed clastic sequence are pitted, probably a consequence of solution near the unconformity. Glauconite grains near the unconformity are oxidized and yellowish.

The unnamed clastic sequence contains the *Rotalipora* (2960 to 2740 feet), *Globotruncana helvetica* (2680 to 2470 feet) and *G. linneiana* (2410 to 2100 feet) foraminifer assemblages, and correspond to the dinoflagellate-spore Zones of *Spinidinium* cf. *vestitum-Eucommiidites minor* (2945 feet), *Cleistosphaeridium polypes* (2876 to 2760 feet), *Surculosphaeridium longifurcatum* (2691 to 2510 feet) and *?Odontochitina operculata* (2370 to 2190 feet). The succession includes strata of Late Albian, Cenomanian, Turonian, Coniacian and/or Santonian, and possibly Early Campanian age. The upper boundary of the unit is placed at the unconformity.

Banquereau Formation (2095 to 900 feet): An unconsolidated, light brown conglomerate at the base of the Banquereau Formation which rests unconformably on the unnamed clastic sequence is overlain by a dark yellowish orange coarse grained sandstone (2095 to 2010 feet). Pebbles in the conglomerate, up to 5.4 mm in diameter, and quartz grains in the sandstone consist largely of vein quartz; plutonic and metamorphic quartz is less common. Quartz grains are well rounded, well sorted, and commonly stained by limonite. Minor constituents of the sandstone are orthoclase, microcline, micropegmatite, perthitic orthoclase, and rare glauconite (some yellow from oxidation), coal fragments, pyrite and molluscs.

The sandstone is overlain at a sharp contact by medium grey glauconitic mudstone (2010 to 1826 feet), enclosing rare nannofossils and foraminifers. In the mudstones are interbedded rare sandy siltstone beds containing fragmentary, thick-shelled molluscs and glauconite.

A sequence (1826 to 1610 feet) of unconsolidated coarse grained feldspathic sandstones with a pebble conglomerate at the base rests with sharp contact upon the underlying mudstones. The feldspar is slightly weathered, perthitic orthoclase. The quartz grains are moderately sorted, well rounded, and have polished (rarely frosted) surfaces; some are yellow. Rare phosphatic nodules consist of glauconite grains, foraminifers and coccoliths cemented by phosphate. In the upper part of the sequence sandstone is interbedded with a siltstone.

The sandstone-siltstone succession grades up into a mudstone sequence (1610 to 900 feet) that in the lower part (1610 to 1430 feet) contains up to 40 per cent glauconite, and phosphatic nodules partly replaced by radial aggregates of dark brownish grey siderite. The high concentration of glauconite and the presence of phosphatic nodules indicate that these mudstones accumulated very slowly. The highly glauconitic mudstone is overlain by beds (1430 to 900 feet) of slightly glauconitic (5 per cent), dark yellowish brown aquaturgid mudstone, rare argillaceous glauconitic siltstone and, at the top, thin beds of calcareous mudstone. Glauconite grains are peloidal and grass green. Bryozoans, pyritized gastropods and narrow pyrite-filled burrows occur in the upper, less glaconitic mudstones.

The Banquereau Formation contains the *Arenobulimina-Globorotalites-Globotruncana* (1860 to 1560 feet) foraminifer assemblage, which possibly is entirely reworked and the *Marginulina decorata* – Pteropod sp. 1 (1510 to 1200 feet), *Globigerina-Turrilina alsatica* (1200 to 990 feet) and *Spiroplectammina carinata* (960 to 900 feet) foraminifer assemblages. It corresponds to the dinoflagellate-spore Zones of *Areoligera senonensis* sensu Gocht, 1969 (1860 to 1830 feet), *Adnatosphaeridium reticulense* (1680 to 1650 feet), *Diphyes colligerum* (1500 to 1470 feet), *Deflandrea heterophlycta* (1110 to 1080 feet) and *Chiropteridium dispersum* (930 to 900 feet). The formation contains strata of Early, Middle and Late Eocene age, and Early and Middle-Late Oligocene age. Younger beds of the Banquereau Formation probably occur in the vicinity of Murre, but samples were not recovered above 900 feet.

BIOSTRATIGRAPHY

I Foraminifers, Ostracods

The diversity of Murre's foraminifer-ostracod assemblages fluctuates considerably. Below approximately 8900 feet shelly microfossils occur only as cavings. Foraminiferal assemblages containing many species and numerous individuals occur at 8000 to 4000 feet (Jurassic), 2680 to 2470 feet (Turonian) and 1000 to 900 feet (Oligocene). Ostracods are rare, except in some Jurassic samples.

Jurassic foraminiferal assemblages in Murre are characterized by the genera *Epistomina, Reinholdella, Garantella,* "*Globigerina*", and several lenticulinid and arenaceous genera. The chronostratigraphy of the assemblages is interpreted by reference to northwestern Europe, Poland and Russia.

Upper Cretaceous deposits are readily subdivided on the basis of their planktonic foraminiferal assemblages, whose chronostratigraphic value in low and mid latitudes is well established. Tertiary assemblages consist largely of benthonic foraminifers having limited chronostratigraphic significance.

Foraminiferal assemblages are listed below in ascending stratigraphic order, as based on the highest occurrence in the well of selected species (*see* also distribution chart, Fig. 3).

Involutina liassica assemblage (Pliensbachian) (8454-7840 feet)

The numerically rich assemblage contains *Brizalina liassica, Epistomina* sp. 12, *Involutina liassica* and *Lingulina tenera,* here taken as indicative of Pliensbachian rocks (*see* also Brouwer, 1969), in agreement with palynological evidence.

Below 8454 feet the fauna is highly impoverished. Sidewall cores down to about 8900 feet contain some unidentified microfossils; below about 8900 feet the microfauna is considered to be caved.

Lenticulina d'orbignyi assemblage (Late Pliensbachian-Toarcian) (7800-6830 feet)

The assemblage contains *Lenticulina d'orbignyi*, *Nodosaria columnaris* and ostracod no. 84 (Klinger), all of which are diagnostic of the Late Pliensbachian-Toarcian (Bartenstein and Brand, 1937; Simon and Bartenstein, 1962; Brouwer, 1969). *Garantella* aff. *rudia* is common, and better preserved than in sediments above 6830 feet.

Garantella ornata and *G.* aff. *rudia* assemblages (Bajocian-Bathonian) (6770-5730 feet)

An assemblage with frequent *G.* aff. *rudia* at 6740-6770 feet is interpreted as Bajocian. A fragment of what might be *G. ampasindavaensis*, a form described from the Bajocian of Madagascar (Espitalie and Sigal, 1963) and common in Amoco Imp. Cormorant N-83, Grand Banks, could be used to put the Bajocian as high as 6260 feet. In light of palynological evidence for Toarcian-Lower Jurassic strata in Murre G-67 as high as 6450 feet in a sidewall core, the presence of a form close to *G. rudia* in Swedish basal Bajocian-Aalenian beds (Norling, 1972), and in Murre G-67 throughout the *Lenticulina d'orbignyi* assemblage thought to be of Late Pliensbachian-Toarcian age, it is possible that in this well *G.* aff. *rudia* indicates uppermost Lower Jurassic strata. The interval 5800-5730 feet is Bathonian, based on data from Poland (Pazdro, 1969a) that *Garantella ornata*, which occurs at this depth ranges as high as Bathonian.

"*Globigerina*" *bathoniana* assemblage (Bathonian) (5700-5260 feet)

This assemblage includes "*Globigerina*" *bathoniana*, *G. balakhmatovae*, *Reinholdella crebra* and *R.* aff. *media*, and is also known from the Amoco-IOE Eider M-75, Cormorant N-83 and Bittern M-62 wells, Grand Banks. The ranges of these markers in the literature indicate a Bajocian-Bathonian age for this assemblage (Pazdro, 1969a, 1969b and Morozova and Moskalenko, 1961). The stratigraphically highest occurrence of these taxa on the Grand Banks is taken as indicative of a Bathonian Age.

Reinholdella crebra var. assemblage (Callovian) (5190-4419 feet)

Richly developed in Murre, the assemblage contains common to frequent *Dorothia* aff. *doneziana*, *Epistomina mosquensis*, *E. uhligi*, "*Globigerina*" *helvetojurassica*, the *Lenticulina quenstedti* group and *Reinholdella crebra* var.; and rare *Ammobaculites suprajurassicus*, *Epistomina regularis*, *Frondicularia franconica*, *Neoflagellina deslongchampsi*, *Nodosaria fontinensis* and *Saracenaris triquetra*. *Reinholdella crebra* var., which on the Grand Banks ranges stratigraphically higher than *R. crebra* Pazdro, is larger, has a more robust test, and a more conical spiral side and (as in Amoco-Imp. Cormorant N-83, Grand Banks) more thickened spiral sutures than the latter. The Callovian Age of the *R. crebra* var. assemblage is based on, (1) the highest occurrence of *Epistomina regularis* (Pazdro, 1969a; Ohm, 1967), (2) the presence of *R. crebra* var. above the Bajocian-Bathonian *R. crebra* (*see* above), and (3) the overall resemblance of the Murre assemblage to the Callovian assemblages of western Germany described by Lutze (1960).

Epistomina mosquensis assemblage (Oxfordian and ?Kimmeridgian) (4419-3445 feet)

This assemblage contains *Epistomina mosquensis*, and *Lenticulina quenstedti* group and Ostracod spp. 10 and 12. It occurs also in Amoco-IOE Eider M-75, Grand Banks, at 3600-2700 feet together with *Lenticulina tricarinella*, *Valvulina meentzeni*, *Gaudryina heersumensis*, *Dorothia doneziana*, *Epistomina uhligi* and *E. soldanii*. The age of this assemblage would be Oxfordian-?Kimmeridgian (*see* Simon and Bartenstein, 1962; Ohm, 1967). In Murre G-67 a carbonate assemblage occurs at 4500-4470 feet with *Cyclogyra* sp. 1 and "*Patellina*" *feifeli* (abundant). Lutze (1960) described the latter species as *Paalzowella feifeli* (Paalzow) from the Oxfordian of western Germany. Another carbonate assemblage at about 4200-3900 feet contains *Ophthalmidium carinatum* (abundant), "*Patellina*", *Pseudocyclammina*, *Trocholina transversarii* (rare) and crinoids (common). Strata between 3445 and 2960 feet contain only mollusc fragments, and accumulated in semirestricted/marginal marine environments.

Rotalipora, *Gavelinopsis cenomanica* assemblage (Cenomanian) (2960-2740 feet)

The assemblage consists of *Gavelinopsis cenomanica* (common), *Rotalipora cushmani* (recovered from cavings at 3770-3740 feet and assumed to originate at 2960-2740 feet) and *R. greenhornensis* (rare), with associated fragmentary molluscs and ostracods. It is interpreted to be shallow marine.

Globotruncana helvetica assemblage (Turonian) (2680-2470 feet)

Murre contains a particularly rich Turonian assemblage. Species include *Cavelinella minima*, *Globotruncana helvetica*, *G. schneegansi*, *Hedbergella amabilis*, *H. bosquensis*, *Lingogavelinella turonica*, *Praeglobotruncana stephani* and *P. turbinata*. The planktonic assemblage seems to belong in Douglas' (1972) low-latitude faunal province. Above 2656 feet the Turonian foraminifers, particularly planktonics, decrease markedly in numbers. This is interpreted to be the result of shallowing of the sea.

Globotruncana linneiana assemblage (Senonian) (2410-2100 feet)

Globotruncana cretacea, G. fornicata, the *G. linneiana* group, *G. marginata* and *Rugoglobigerina aprica* characterize this numerically poor, shallow marine assemblage.

Arenobulimina-Globorotalites-Globotruncana assemblage (?reworked Senonian) (1860-1560 feet)

This assemblage is of Senonian age and includes *Arenobulimina* sp. 1, *Gavelinella* sp. 2 (common), *Globorotalites michelinianus* (common) and *Globotruncana fornicata.* Tests are abraded, occur in coarse sandstones, and provisionally are interpreted as being reworked because of an Eocene dinoflagellate assemblage at this depth.

Marginulina decorata-Pteropod sp. assemblage (Late Eocene) (1510-1200 feet)

The assemblage contains a few specimens of the *Marginulina decorata* group, *Epistomina, Cibicides,* and bryozoans, solitary corals and Pteropod sp. 1. The latter has been recognized in several Grand Banks wells (Amoco-Imp. Petrel A-62, Bittern M-62, Jaeger A-49, and Elf Hermine E-94) where its top (local extinction point) occurs in rocks dated Late Eocene on the strength of *Globorotalia centralis* and Late Eocene dinoflagellates. *Marginulina decorata* according to Simon and Bartenstein ed. (1962) is typical of the northwest Germany Eocene.

Globigerina-Turrilina alsatica assemblage (Oligocene) (1200-900 feet)

Turrilina alsatica, a Grand Banks Oligocene marker tops at 990 feet. It occurs with *Globigerina* aff. *ciperoensis, G. praebulloides* (entered in Fig. 3 as *Globigerina*) and the *Marginulina decorata* group at 1020-1050 feet.

Spiroplectammina carinata assemblage (Oligocene-Miocene) (960-900 feet)

The assemblage contains common *Spiroplectammina carinata, Ceratobulimina contraria, Nodosaria* sp. 8 and *Guttulina problema,* which on the Labrador Shelf (in Tenneco *et al.* Leif E-38 at 3200-2100 feet) occur with a pelagic assemblage thought to be Miocene. The Murre assemblage also contains *Gyroidina girardana* which in Leif E-38 occurs in beds provisionally dated Oligocene-Miocene. In northwestern Europe *G. girardana* has been recorded from the Eocene to Miocene, and particularly from the Oligocene, whereas *Spiroplectammina carinata* is particularly characteristic of Oligocene to Miocene deposits (Simon and Bartenstein, ed., 1962). Consequently, this assemblage is considered likely to be Oligocene-Miocene in age. It also contains *Epistomina elegans, Cibicides ungerianus, Bolivina marginata* var. *costata, Pullenia subcarinata, Eggerinella* sp. 1, *Dorothia* and *Eggerella,* solitary corals, bryozoans and molluscs.

II Dinoflagellates and Spores

Palynological analyses of the interval 10 620-900 feet in Amoco-IOE Murre G-67 has revealed the presence of Devonian, Jurassic, Cretaceous and Tertiary rocks. The Early Cretaceous is represented by one sample dated Albian; the Tertiary includes the Eocene and Oligocene only.

The proportion of terrigenous (spores) to marine (dinoflagellates) organic microfossils varies considerably within this well. Exclusively terrigenous assemblages occur in the Devonian (10 620-10 350 feet), Hettangian-Pliensbachian (9571-7960 feet), Kimmeridgian-?Tithonian (3624-3114 feet) and Albian (2945 feet) intervals; whereas mixed assemblages of marine and terrigenous organic microfossils occur from the Late Pliensbachian to Kimmeridgian (7870-3650 feet) and throughout the Late Cretaceous and Tertiary (2876-900 feet). The Devonian is dated on spores, chitinozoans and acritarchs. The Early and Middle Jurassic is primarily subdivided on the basis of characteristic dinoflagellate-spore assemblages, whereas the Late Jurassic, Cretaceous and Tertiary successions are referred to Williams' (1975) dinoflagellate-spore zonation.

For description of Zones and Assemblages (*see* also Figs. 2 and 3).

Hystricosporites-Sphaerochitina spore-chitinozoan assemblage (Middle-Late Devonian) (10 620-10 350 feet)

The assemblage is impoverished and is preserved in metasediments. Marine microfossils include two species of the acritarch genera *Micrhystridium* Deflandre and *Veryhachium* Deunff, and the chitinozoan *Sphaerochitina* Eisenack. With these occurs a species of trilete spore having large anchor-shaped processes perhaps referable to *Hystricosporites* McGregor.

Heliosporites reissingeri assemblage (Hettangian-Sinemurian) (9541-8781 feet)

Spores include *Classopollis classoides* Pflug emend. Pocock and Jansonius, *Heliosporites reissingeri* (Harris) Chaloner, and *Perinopollenites elatoides* Couper.

Cerebropollenites mesozoicus assemblage (Pliensbachian) (8766-7330 feet)

Spores present are *Camarozonosporites* Pant ex Potonié emend. Klaus, *Cerebropollenites mesozoicus* (Couper) Nilsson, common *Classopollis classoides, C. simplex* (Danze-Corsin and Laveine) Reiser and Williams, and *Vitreisporites pallidus* (Reissinger) Nilsson. *Nannoceratopsis gracilis* Alberti, present in sidewall cores in the interval 7870-7330 feet is not

known from sediments older than Late Pliensbachian. This interval is therefore tentatively dated Late Pliensbachian.

Nannoceratopsis gracilis assemblage (Toarcian-Aalenian) (7223-6450 feet)

Dinoflagellates present include *Mancodinium semitabulatum* Morgenroth, *Nannoceratopsis gracilis* and *Pareodinia ceratophora* Deflandre emend. Gocht. The spores *Callialasporites dampieri* (Balme) Dev and *Contignisporites* Dettmann do not range down into older sediments. The top of the *Nannoceratopsis gracilis* assemblage is picked from a sidewall core at 6450 feet. The topmost cuttings sample which is assignable to this assemblage is from 6830-6860 feet. The latter pick is identical to the top of the foraminifer *Lenticulina d'orbignyi* assemblage which is dated Late Pliensbachian-Toarcian.

Ctenidodinium pachydermum assemblage (Bajocian) (6355-5992 feet)

The few species include the dinoflagellates *Ctenidodinium pachydermum* (Deflandre) Gocht and *Tenua rioulti* Sarjeant, and the spore *Contignisporites cooksonii* (Balme) Dettmann.

Gonyaulacysta filapicata assemblage (Bathonian) (5900-5270 feet)

Similar in some respects to the German Bathonian dinoflagellates described by Gocht (1970), this assemblage contains the dinoflagellates *Ctenidodinium ornatum* (Eisenack) Deflandre, *Gonyaulacysta filapicata* Gocht and *Leptodinium subtile* subsp. *pectinigerum* Gocht.

Valensiella vermiculata Zone (Callovian) (5260-4445 feet)

This zone contains more species than the overlying Oxfordian. Species present include *Gonyaulacysta* cf. *aldorfensis* Gocht, *Meiourogonyaulax* sp. Williams (1975), *Pareodinia ceratophora* and *Valensiella ovulum* (Deflandre) Eisenack, and the spore *Cerebropollenites mesozoicus* (Couper) Nilsson.

Gonyaulacysta jurassica Zone (Oxfordian) (4419-4070 feet)

The impoverished flora includes the zonal species *Gonyaulacysta jurassica* (Deflandre) Norris and Sarjeant.

Gonyaulacysta cladophora Zone (Kimmeridgian) (4058-3650 feet)

Genus et sp. 2 Gocht 1970, *Gonyaulacysta cladophora* (Deflandre) Dodekova, *Lanterna sportula* Dodekova and *Wanaea spectabilis* (Deflandre and Cookson) Cookson and Eisenack, are present in this interval.

Leptolepidites psarosus assemblage (Kimmeridgian-?Tithonian) (3624-3114 feet)

Spores are the only organic microfossils in this interval. They include numerous *Callialasporites dampieri, C. trilobatus* (Balme) Dev, *Densoisporites perinatus* Couper, *Foraminisporis wonthaggiensis* (Cookson and Dettmann) Dettmann, *Leptolepidites psarosus* Norris and *Vitreisporites pallidus* (Reissinger) Nilsson. The interval 4419-3445 feet is assigned to the foraminifer *Epistomina mosquensis* assemblage which is Oxfordian-Kimmeridgian. The interval from 3445-3114 feet, which contains no microfossils other than the *Leptolepidites psarosus* assemblage, may be Tithonian.

Spinidinium cf. *vestitum-Eucommiidites minor* Zone (Albian) (2945 feet)

All organic microfossils in this zone in Murre G-67 are terrigenous spores. They include *Appendicisporites jansonii* Pocock, *A. problematicus* (Burger) Singh, *Callialasporites dampieri, Costatoperforosporites fistulosus* Deak and *Liliacidites peroreticulatus* (Brenner) Singh. The angiosperm pollen *Retitricolpites virgeus* (Groot, Penny and Groot) Brenner, indicates that the strata at 2945 feet are no older than Late Albian.

Cleistosphaeridium polypes Zone (Cenomanian) (2876-2760 feet)

Contains only spores at 2876 and 2764 feet and the dinoflagellates *Cleistosphaeridium polypes* subsp. A Williams (1975), *Cyclonephelium vannophorum* Davey and *Litosphaeridium siphoniphorum* (Cookson and Eisenack) Davey and Williams at 2810 and 2760 feet.

Surculosphaeridium longifurcatum Zone (Turonian) (2691-2510 feet)

Species not extending into younger sediments are *Canningia colliveri* Cookson and Eisenack, *Chlamydophorella nyei* Cookson and Eisenack and *Trichodinium castanea* (Deflandre) Clarke and Verdier, and the spores *Camarozonosporites insignis* Norris, *Cicatricosisporites hallei* Delcourt and Sprumont and *Classopollis classoides*.

Coniacian-Santonian (2440-2380 feet)

Species present include the dinoflagellates *Palaeohystrichophora infusorioides* Deflandre and *Surculosphaeridium longifurcatum* (Firtion) Davey *et al.*

?*Trichodinium castanea* informal subzone of the *Odontochitina operculata* Zone (Early Campanian) (2370-2190 feet)

The interval 2370-2190 feet is provisionally referred to the early Campanian informal subzone of *Trichodinium castanea*, but it possibly belongs to the

older zone(s) of *Oligosphaeridium pulcherrimum* (Coniacian) and/or *Hystrichosphaeridium truncigerum* (Santonian). It contains the dinoflagellates *Australiella victoriensis* (Cookson and Manum) Lentin and Williams, *Deflandrea echinoidea* Cookson and Eisenack, *Dinogymnium euclaensis* Cookson and Eisenack and *Hystrichosphaeridium recurvatum* (White) Davey and Williams, and the spore *Rugubivesiculites convolutus* Pierce.

Areoligera senonensis Zone (Early Eocene) (1860-1830 feet)

This interval contains the dinoflagellate *Wetzeliella homomorpha* Deflandre and acritarch *Comasphaeridium* cf. *cometes* (Valensi) Staplin, Jansonius and Pocock.

Samples are lacking between 2190 feet (early Campanian or Santonian) and 1860 feet (Eocene), so the stratigraphic relationship between the Cretaceous and Tertiary in Murre G-67 is not known. An unconformity may exist between ?Early Campanian or Santonian and Eocene strata and, for want of data, this interpretation is provisionally followed. It is possible, however, that Maastrichtian and Paleocene rocks also occur in the well. One specimen of *Danea mutabilis* Morgenroth, a dinoflagellate known only from the Early Paleocene, was found in cuttings (presumably caved) from 2220-2190 feet.

Adnatosphaeridium reticulense Zone (Middle Eocene) (1680-1650 feet)

The dinoflagellates *Adnatosphaeridium vittatum* Williams and Downie, *Cordosphaeridium cracenospinosum* Davey and Williams, *Dinopterygium cladoides* Deflandre *sensu* Morgenroth, *Homotryblium tenuispinosum* Davey and Williams and *Lanternosphaeridium axiale* (Eisenack) Morgenroth have been recorded from this one cuttings sample.

Diphyes colligerum Zone (Late Eocene) (1500-1470 feet)

Two dinoflagellate species, *Areoligera* cf. *senonensis* Lejeune-Carpentier and *Wetzeliella varielongituda* Williams and Downie, characterize the zone in Murre G-67.

Deflandrea heterophlycta Zone (Early Oligocene) (1110-1080 feet)

Species not ranging into younger sediments are the dinoflagellates *Areosphaeridium arcuatum* Eaton, *Gonyaulacysta* cf. *granulata sensu* Benedek, *Lejeunia tenella* Morgenroth, *Phthanoperidinium* Drugg and Loeblich and *Wetzeliella coleothrypta* Williams and Downie.

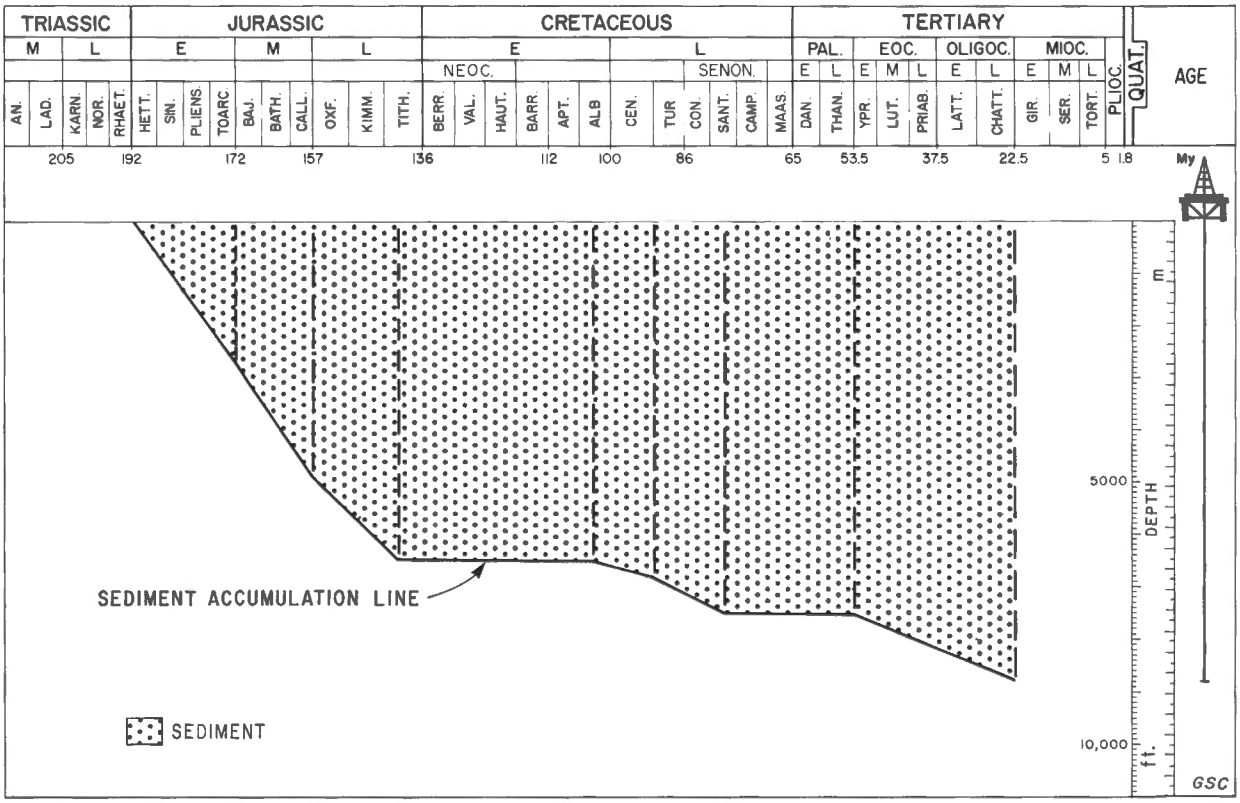

Figure 5. Sediment accumulation in Murre G-67 from Hettangian through Oligocene time.

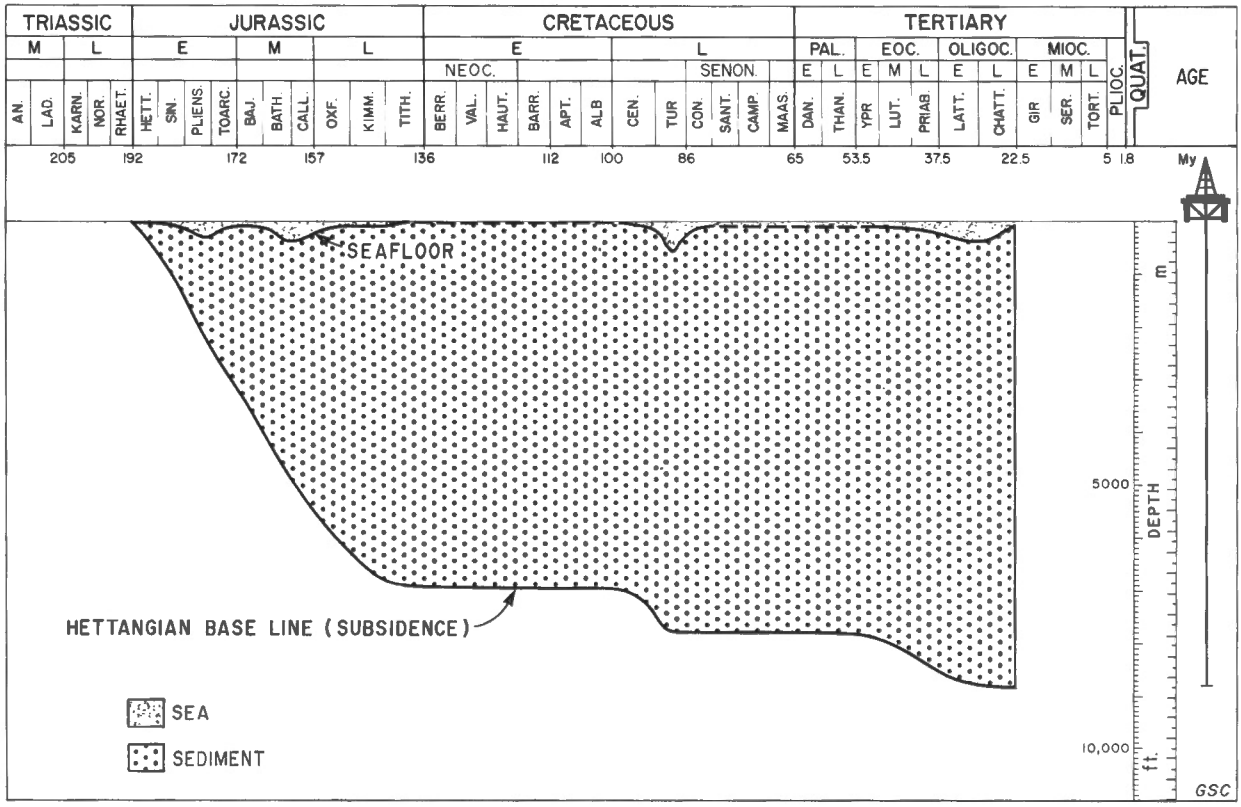

Figure 6. Depositional environment and subsidence in Murre G-67 — Grand Banks.

Chiropteridium dispersum Zone (Middle-Late Oligocene) (930-900 feet)

This interval contains the dinoflagellates *Chiropteridium aspinatum* (Gerlach) Brosius, *Deflandrea spinulosa* Alberti, *Impletosphaeridium transfodum* Morgenroth, *Polysphaeridium pastielsi* Davey and Williams, *Tanyosphaeridium* sp. A Williams and Brideaux and *Tubidermodinium sulcatum* Morgenroth.

DEPOSITIONAL HISTORY

The depositional history of the Murre G-67 strata is based on a synthesis of paleoecologic, sedimentologic and chronostratigraphic data. A graphic representation of the depositional history is in Figures 2 and 6.

Unnamed metasedimentary rocks (10 949 T. D. to 10 350 feet)

Acritarchs in the "basement" rocks encountered at the bottom of Murre G-67 indicate marine deposition in Middle and/or Late Devonian times, as previously noted. The nature of the marine environment has not been determined. Fine interlayering of arenaceous and silty laminae with argillaceous material in this rock is comparable to the rhythmic lamination commonly found in Recent tidal flat and estuarine sediment. On the other hand, the poorly sorted nature of much of the sediment is evocative of turbidites and associated sediments that characterize deeper-marine deposition.

The marine setting in which these sediments were deposited contrasts with the terrestrial conditions that prevailed during Middle and Late Devonian times over most of the Appalachian region. This Appalachian landmass probably lay within several hundred miles of, and possibly even connected with, the Old Red landmass of Britain and northern Europe, if the widely accepted hypothesis that northern Europe was sutured to North America during the Devonian is correct. Marine conditions prevailed in a geosynclinal belt to the south of the Old Red landmass, however, is indicated by the Devonian marine sequences of Devon, Cornwall, Brittany, Belgium, and the Rhineland (Aubouin, 1965; Anderson and Owen, 1968). This mid-European Geosyncline has been extrapolated to pass through the approximate area of the Murre well (Bard *et al.*, 1971; Dewey and Burke, 1973). Hence, the Devonian rocks in Murre G-67 could be related tectonically to those of the mid-European Geosyncline. If so, the Hercynian earth movements that affected the mid-European Geosyncline presumably also had some effect on the Devonian rocks in Murre G-67, perhaps imparting to them their metamorphic foliation (previously described under Lithostratigraphy). An alternative interpretation is that the Devonian sediments in Murre G-67 were deposited in a seaway that developed on the eastern flank of the Appalachian Belt and which

genetically, was unrelated to the mid-European Geosyncline. In this event, the metamorphic effects are more likely to have developed during a late phase of the Devonian Acadian Orogeny.

Unnamed red beds (10 350 to 9590 feet)

Red beds accumulated to a thickness of 760 feet upon the erosional surface that truncates the Devonian metasediments. The red beds are continental, and accumulated under arid climatic conditions at a time of little physiographic relief. The upper beds may have formed in a continental sabkha, or coastal sabkha environment. The entire sequence is barren and has yielded no paleontological evidence for its age. From the geological evidence Jansa and Wade (1975) suggest a Triassic age for the red beds.

Iroquois Formation (9590 to 8454 feet)

A marine transgression during Early Jurassic (Hettangian-Pliensbachian) time ended continental deposition in the Murre G-67 area and gave rise to a succession of progressively deeper-water sediments which are referred to the Iroquois Formation. The first of these were hypersaline, semirestricted lagoonal and tidal flat deposits (lower Iroquois Formation, 9590 to 9220 feet) laid down directly above the red beds. The water circulation improved during deposition of the middle Iroquois Formation (9220 to 8815 feet), and lagoonal sediments lacking halite accumulated in an environmental setting that in other respects was similar to that of the lower Iroquois Formation. Inner neritic conditions prevailed during deposition of the upper Iroquois Formation (8815 to 8454 feet). Terrigenous spores are the only microfossils in the lower and middle Iroquois Formation. Characteristic are *Camarozonosporites* sp., *Heliosporites reissingeri* and *Perinopollenites elatoides*. In the upper Iroquois Formation the same spore assemblage and some poorly preserved unidentified foraminifers, ostracods, crinoids and mollusc fragments occur.

Only two intervals in the Mesozoic-Cenozoic succession of Murre G-67 lack shelly microfossils, and they correspond to the only two intervals where organic-microfossil assemblages consist solely of terrigenous spores. The intervals are the lower and middle Iroquois Formation and the upper part of the "Mic Mac" Formation.

Whale Unit (8454 to 3740 feet)

The fine grained character of the Whale shale (8454 to 6588 feet), the nodosariid, *Epistomina-Garantella* assemblage (8550 to 6700 feet) rich in specimens, and the appearance at 7870 feet of dinoflagellates and acritarchs indicate neritic deposition that continued uninterrupted from Pliensbachian to Toarcian-Bajocian time.

The first detectable shallowing of the Jurassic sea took place during the Toarcian-Bajocian and led to the very shallow marine conditions of Bajocian time, during which the Whale limestone (6588 to 5960 feet) was deposited. The foraminiferal assemblage consists only of *Trocholina* and a few specimens of *Garantella*, in contrast to the richer foraminiferal assemblage below 7600 feet.

Above 5800 feet, and especially between 5400 and 4500 feet, a rich and diversified foraminiferal assemblage with "*Globigerina*", *Reinholdella*, *Epistomina* and numerous nodosariids of Bathonian-Callovian age indicates more widespread marine (middle to outer neritic) conditions than existed earlier. During this period the fine grained clastic sediments of the upper shale-limestone member of the Whale unit were deposited.

Oxfordian-Kimmeridgian sediments (approximately 4500 to 3900 feet) contain a foraminiferal assemblage of "*Patellina*", *Cyclogyra* (abundant), *Trocholina* and *Pseudocyclammina* (rare), reflecting the carbonate lithology and indicating shallower marine conditions than prevailed during deposition of the underlying strata.

"Mic Mac" Formation (3740 to 2975 feet)

The uppermost Whale unit and all of the "Mic Mac" Formation (approximately 3900 to 2975 feet) of Kimmeridgian-?Tithonian age contain few marine microfossils. The upper 475 feet of the "Mic Mac" sediments contain only terrigenous organic microfossils. This microfossil assemblage together with the oolitic carbonate-sand lithology indicates a marginal marine environment.

Unnamed clastic sequence (2975 to 2095 feet)

A major unconformity separates Upper Jurassic deposits of the "Mic Mac" Formation from the upper Albian unnamed clastic sequence. Consequently, an unknown thickness of sediments may have been laid down and subsequently eroded in the vicinity of Murre G-67 during Early Cretaceous time.

During deposition of the lower half (2975 to 2600 feet) of the unnamed clastic sequence (Late Albian, Cenomanian and Early Turonian time), conditions changed gradually, deepening steadily from dominantly continental to dominantly marginal marine (spores, very few foraminifers) and eventually to outer neritic (rich in planktonic and benthonic foraminifers). The relatively deep water conditions lasted only during the Turonian before a marine regression during Late Turonian and Early Senonian time brought about the progressively shallower, inner neritic to marginal marine conditions that are represented in the upper half (2600 to 2095 feet) of the sequence. This change in environments is clearly evident from the foraminifera fauna which above 2400 feet consists of only a few specimens of benthonic and planktonic taxa.

The Cretaceous depositional record may terminate abruptly at an unconformable contact between Early Senonian marginal marine deposits at the top of the unnamed clastic sequence and Eocene nonmarine/near-shore conglomerates at the base of the overlying Banquereau Formation. However, the possibility exists

that Maastrichtian and Paleocene rocks do occur between 2100 and 1860 feet but that inadequate sample coverage across the interval does not indicate them. One specimen of *Danea mutabilis* Morgenroth, a dinoflagellate known only from the early Paleocene, was found in cuttings (presumably caved) from 2220 to 2190 feet.

Banquereau Formation (2095 to 900 feet)

Sediments in Murre G-67 referred to the Banquereau Formation accumulated during Eocene and Oligocene time in environments that became progressively slightly deeper, until Middle Late Oligocene time. The Eocene deposits (2095 to 1200 feet) include, successively, a basal conglomerate and coarse sandstone, laid down under high energy nearshore/nonmarine conditions, brackish/shallow neritic mudstone, a distributary mouth bar or sand barrier deposit at 1830 to 1710 feet, and shallow neritic glauconitic mudstones (1610 to 1430 feet) that accumulated very slowly. The microfossil assemblage from approximately 1800 to 1560 feet contains some dinoflagellates and foraminifers, the latter provisionally considered reworked from the Upper Cretaceous. A shallow marine assemblage with specimens of *Marginulina, Cibicides, Epistomina* and some bryozoans, solitary corals and a Pteropod occurs from 1200 to 1510 feet.

Throughout the Lower Oligocene interval (1200 to 990 feet) glauconitic mudstones continued to accumulate; the foraminifera assemblage with *Turrilina, Globigerina* spp., *Eponides umbonatus, Pullenia bulloides, Uvigerina* aff. *peregrina* and *Nonion affine* indicates deeper marine, possibly outer shelf, conditions than those in the Eocene.

The 990- to 900 foot interval, dated Middle Late Oligocene, may be of somewhat shallower marine character with a foraminifera assemblage containing no planktonics, common *Spiroplectamina, Ceratobulimina, Nodosaria* and *Guttulina* and some solitary corals, bryozoans and molluscs fragments.

SUBSIDENCE AND SEDIMENTATION

We have attempted to reconstruct the history of subsidence and sedimentation in Murre G-67 from the beginning of Hettangian to the close of Oligocene time (Figs. 5, 6) (*see* also Gradstein *et al.*, in press). The amount of subsidence or uplift (vertical movement) at a well site during a given time may be deduced from the amount of sediment accumulated at that site during that period and the change in paleo-water depth. When the sea has deepened over a period of time, the vertical movement is equal to the sum of change in paleo-water depth and the thickness of sediment accumulated during the period. When the sea has become shallower, the vertical movement equals the thickness of sediment accumulated less the change in paleo-water depth.

The stratigraphic and depositional environment data are taken from Figure 2. The radiometric time scale is a composite of that of Harland ed. (1964, p. 199, 204, 208) for the Triassic, Jurassic and earliest Cretaceous, van Hinte (1972) for most of the Cretaceous, and Berggren (1972) for the Cenozoic. The history of Murre G-67 outlined is somewhat generalized because of the preliminary nature of the pre-Tertiary time scale and because of possible errors in the age and water depth interpretations. Some subsidence and sedimentation rates calculated here differ slightly from the ones in Gradstein *et al.* (in press), which were based on less stratigraphic information.

In calculating the rates of subsidence and sedimentation in Murre G-67 it has been assumed that:

1. The Hettangian is complete;
2. The Toarcian/Bajocian boundary is at 6800 feet;
3. The ?Tithonian is Lower Tithonian;
4. The Albian is upper Albian;
5. The Senonian only includes the Coniacian and half of the Santonian;
6. Eocene rocks occur throughout the inadequately sampled interval 2100-1860 feet; and
7. Sedimentation was continuous unless indicated otherwise.

In Hettangian-Toarcian and Bajocian-Callovian times sediment accumulated at the Murre G-67 site at the rate of 4-5cm/1000 yr. slowing to 2.5 cm/1000 yr. in the Oxfordian-Early Tithonian (Fig. 5). After prolonged non-deposition or erosion, sedimentation was renewed in the Late Albian-Cenomanian at 0.6 cm/1000 yr., increasing to 1.6 cm/1000 yr. in the Turonian-Early Senonian. Eocene and Oligocene deposits accumulated at 1.2 cm/1000 yr.

The subsidence rates for the Murre G-67 site, which are graphically expressed by the "Hettangian base line" in Figure 6, are minimum estimates since no account has been taken of compaction and possible erosion. During the Jurassic the Murre site subsided relatively rapidly at an average rate of 3.8 cm/1000 yr. A comparison of the magnitude of the changes in water depth with the magnitude of the site's rate of subsidence during the Jurassic Period shows that changes in water depth were minor fluctuations in the general pattern of sedimentation. On the average, sedimentation and subsidence were virtually in balance. No estimates have been made of how much sediment accumulated during latest Jurassic to Early Albian time and was subsequently eroded prior to the onset of Late Albian deposition.

Albian-Cenomanian subsidence of less than 1 cm/1000 yr. increased early in the Turonian to about 6 cm/1000 yr. In the Late Turonian and Early Senonian the rate fell to near zero, and sedimentation took place unaccompanied by subsidence. Lack of data, stemming from inadequate sample coverage, prevents us from determining if vertical movements took place at Murre G-67 during Late Senonian time. Eocene and Oligocene subsidence was in the order of 1-2 cm/1000 yr., decreasing toward the end of the Oligocene.

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