2N EOR NOR. 38 ROB. RESEARCH

ROBERTSON RESEARCH INTERNATIONAL LIMITED

REPORT NO. 4860P/C

00734.

PETROGRAPHIC AND SCANNING ELECTRON MICROSCOPY ON 67 SAMPLES FROM THE INTERVAL 3693.1m – 3739.35m (TOR AND UPPER HOD FORMATIONS) IN THE 2/11 - 6 WELL, NORWEGIAN NORTH SEA.

by

V. H. HITCHINGS
C. K. PETER

PROJECT NO. RRPS/823/C/23198

Prepared by:

Robertson Research International Limited,
Ty'n-y-Coed,
Llanrhos,
Llandudno,
Gwynedd LL30 1SA,
Wales,
U.K.

Prepared for:

Amoco Norway Oil Company,
Postboks 388,
Bergjelandsgate 25,
4000 Stavanger,
Norway.

November, 1982

ROBERTSON RESEARCH

CONTENTS

FIGURES

PLATES

APPENDICES

ENCLOSURES

1. DATA SUMMARY LOG, TOR AND UPPER HOD FORMATIONS, SCALE 1:200
2. FAUNAL/FLORAL DISTRIBUTION CHART, TOR AND UPPER HOD FORMATIONS, SCALE 1:200

SUMMARY AND CONCLUSIONS

Petrographic thin sections of core chips from the Tor and Upper Hod Formations (Chalk Group) of the 2/11-6 well, Hod Field, offshore Norway, have been analysed and the results integrated with scanning electron microscope and X-ray diffraction data supplied by Amoco. Particular emphasis has been placed on environmental interpretation and the effects of diagenesis, with a view to achieving an explanation for the reservoir characteristics of the studied section.

The sequence examined comprises pelagic and hemipelagic limestones dominated by planktonic foraminifera and coccolith platelets. Deposition of the Upper Hod took place largely in an open marine outer shelf environment, although an overall shallowing during the time of deposition gave rise to inner shelf conditions. An unconformity or hiatus has previously been interpreted from biostratigraphic analysis at the top of the Upper Hod Formation. The overlying Tor Formation accumulated in a marine inner shelf environment with good open marine circulation.

The depositional fabrics of the limestones have been altered to varying degrees by diagenesis. The effects of cementation, dissolution, fracturing and stylolite formation have all been recorded, and the varying intensity or extent of these processes are largely responsible for the variation in petrophysical characteristics of the cored sequence.

The limestones tend to have high chalky porosities, but low permeabilities. Tighter zones where porosity and permeability are considerably reduced by cementation, are related to hardground formation at or near the sediment surface. These hardgrounds formed during a hiatus or unconformity at the top of the Upper Hod Formation.

CHAPTER 1

INTRODUCTION

This report contains the results of geological studies carried out on sixty-seven samples from the 2/11-6 well, Hod Field, Norwegian North Sea. The studies were commissioned by Amoco Norway Oil Company, with the objectives of describing basic geological data on facies types, diagenesis and reservoir characteristics. The sequence examined represents the Tor and part of the Upper Hod Formations, Chalk Group.

Material Available for Study

Amoco Norway supplied RRI with sixty-six thin sections (which had previously been half stained with alizarin red-S and potassium ferricyanide), scanning electron micrograph plates of sixty-seven samples, and accompanying X.R.D. analyses (Amoco Production Co., Tulsa, Oklahoma, Job numbers 82-288 and 82-306). Also supplied were the porosity, permeability, oil saturation, water saturation and grain density measurements performed on the samples by Keplinger Laboratories Inc.. Amoco also supplied a 1:200 LDL/CNL/G log for the interval 3525m to 3820m. This study has followed a stratigraphic study of the 2/11-6 (RRI Report No. 2788P/A) which has been used to provide the stratigraphic framework.

Work Programme

The following analyses were requested by Amoco Norway:

1. A standard petrographic analysis, describing the mineralogy, grain composition, grain types and any degree of crystal orientation.
2. Grain contacts, pressure solution features, secondary cement and type of cement.
3. Porosity, fractures and cementation of fractures, secondary infill of calcite in foraminifera and pores.
4. If possible, any environmental interpretation.

To this end the following work programme was followed:

1. A correlation of the porosity data with the CNL trace to achieve a core to log adjustment.
2. Petrographic analyses were conducted on the thin sections to obtain detailed information on the distribution of original particle types and the diagenetic characteristics, with particular reference to pore type, size and distribution, and the effects of diagenesis on these.
3. The preparation of photomicrographs to illustrate the facies and diagenetic characteristics of the sequence.
4. Analysis of the scanning electron micrographs for nannofabrics and any diagenetic effects evident at this level, with special reference to the porosity present.
5. Computer plotting of the porosity and permeability data to illustrate and define units.
6. Preparation of a report for the well giving descriptions of facies, nannofabrics, diagenesis, and depositional environments; illustrated with 1:200 scale data summary logs and photographic material. Included in this report is the integration of reservoir units with respect to facies, nannofabrics, diagenesis and X.R.D. data.

Presentation of Results

The results of the study are presented in this report under the headings listed in the contents. Accompanying the text and photographic material is a data summary log (Enclosure 1) and a faunal/floral chart (Enclosure 2).

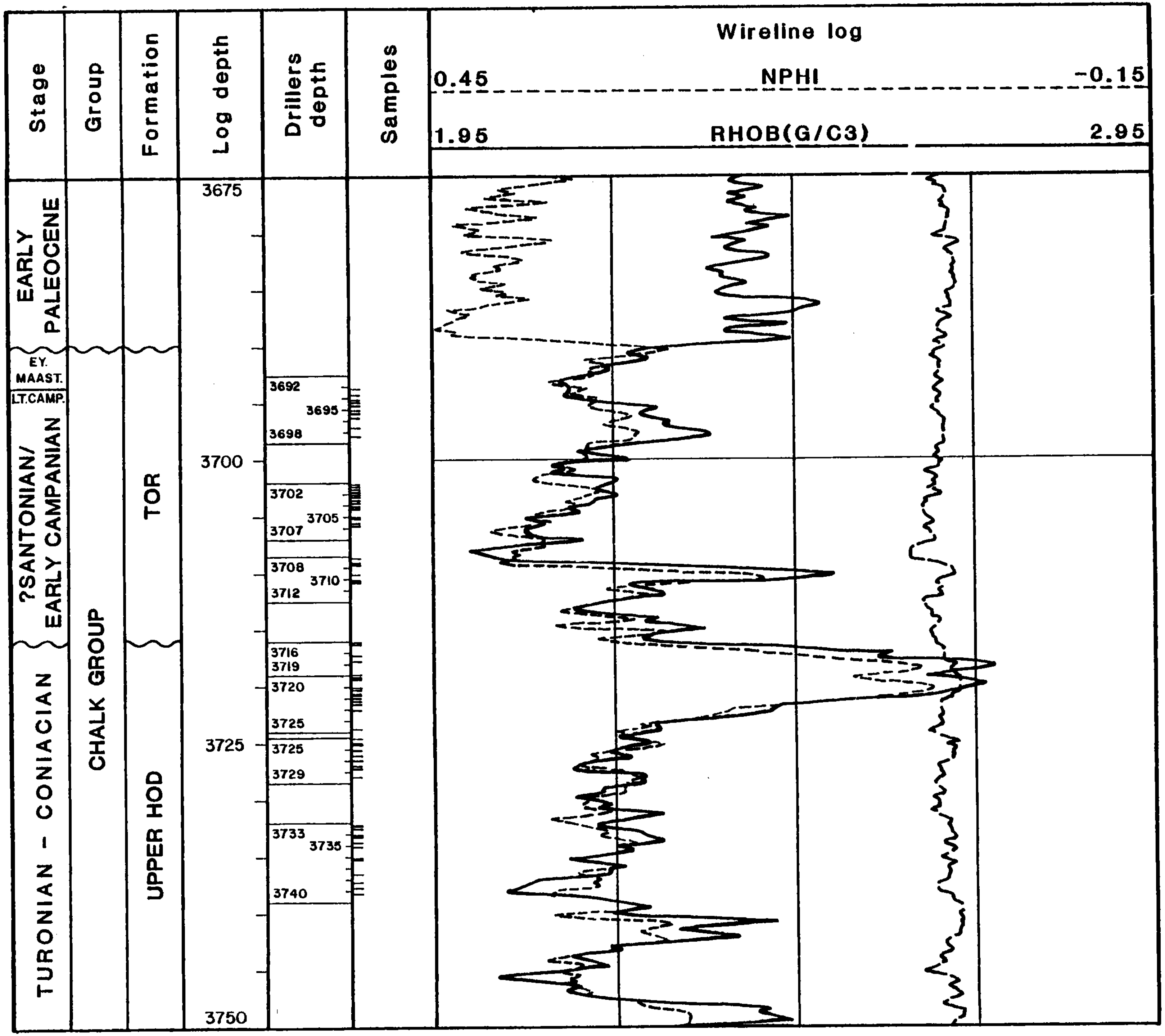


FIGURE 2 Stratigraphy, sample positions and CNL/FDC log for the 2/11 - 6 well. (TOR and UPPER HOD FORMATIONS)

CHAPTER 2

INTERVAL DESCRIPTIONS

The sequence examined, from the Tor and Upper Hod Formations of the 2/11-6 well, has been divided into seven intervals on the basis of petrography, scanning electron microscopy, X-ray diffraction analyses and wireline log traces. These intervals are described below in terms of their lithology, scanning electron microscopy, fauna and flora, diagenesis, porosity and permeability. Figure numbers refer to the S.E.M. plates provided by Amoco. (Job numbers 82-288 and 82-306). Porosity and permeability quoted values are from core analysis, but assessment of percent pore type is from visual inspection of thin sections. All depths quoted are drillers depths.

TOR FORMATION

INTERVAL 3693.1m-3697.4m

Lithology

Lithologically this interval consists of lime mudstones comprising unabraded intact or fragmented foraminifera and bioclasts in a porous lime mud matrix. Petrographic analysis indicates that clay is locally distributed in foraminifera chambers, whilst X.R.D. analysis records up to 1% illite and trace amounts of kaolinite in these rocks.

Scanning Electron Microscopy

The scanning electron microscopy results show the following features within the samples examined:

(i) There is no apparent orientated fabric within the rock matrix.

(ii) The 'crystals' of the matrix are generally well 'rounded' and appear to vary in size from 0.5μm to 5μm (excluding coccoliths).

(iii) Peloidal or micropelletoidal grains are locally evident (e.g.3693.1m).

(iv) Compromise boundaries occur as triple junctions between adjacent crystals in peloidal or micropelletoidal grains.

(v) Coccoliths present show evidence of overgrowth cementation, evident from the loss of constituent platelet boundaries (3694.1m; Figure 2D); and subsequent dissolution as the platelet crystals are 'rounded-off'.

(vi) Disseminated pyrite framboids are locally distributed (3694.1m; Figures 2B, 2C).

Fauna and Flora

The fauna of the interval consists of recurrent (frequent to common) planktonic foraminifera, bivalves and ostracods. Benthonic rotalid foraminifera are commonly distributed, whilst textularids and echinoderm debris are sparsely distributed. Nannofossils are evident upon S.E.M. examination and much of the matrix material is probably disaggregated coccolith debris.

Diagenesis

The major diagenetic features in this interval are best seen in S.E.M. examination and consist of:

(i) the overgrowth cementation of the sediment (which is predominantly matrix material).

(ii) the corrosion of the overgrowth cement, resulting in the rounded appearance of the grains.

Overgrowth cementation in North Sea chalks is regarded as of marine phreatic origin (Neugebauer, 1974; Scholle, 1974; Mapstone, 1975; Hardman and Kennedy, 1980). Intragranular cementation within this interval is locally apparent (3694.35m, 3697.4m) from petrographic analysis, where blocky calcite infills the foraminifera chambers (this may account for up to 5% B.V.). The blocky calcite cements appear (at 3697.4m) to be associated with pressure solution planes, which are now lined with clay minerals. The material mobilised at the solution plane now cements the foraminiferal chambers.

Minor diagenetic effects recorded within this interval include the crystallisation of pyrite and authigenic euhedral quartz.

Porosity and Permeability

Porosity; range 24.2% to 34.6%, average 31.1%.

Permeability; range 0.29md to 1.76md (only three measurements available).

Much of the porosity in this interval is of matrix origin, although 2% to 8% intragranular porosity is also present. The S.E.M. examination shows that the pores are interconnected, although the small size of pore throats accounts for the low permeabilities recorded.

3697.4m-3702.2m Gap (4.8m)

INTERVAL 3702.2m-3705.85m

Lithology

This interval consists primarily of lime mudstones. Intragranular cements occur within foraminifera chambers and occupy up to 6% (B.V.) of the rock. Clay is present in solution planes, foraminifera chambers and within the rock matrix, but only accounts for trace proportions of the rock composition (according to X.R.D. results).

Scanning Electron Microscopy

The scanning electron micrograph plates show the following characteristics:

(i) the matrix material has no apparent orientation.

(ii) the constituent matrix crystals are often angular and many are evidently disaggregated coccolith plates (i.e. platelets); the matrix crystals vary in size from 0.3µm to 2µm (excluding coccoliths).

(iii) coccoliths are abundant and occasionally rhabdoliths occur e.g. 3705.6m.

(iv) the coccoliths vary greatly in size and presumably species.

(v) locally e.g. at 3703.35m (Figure 15D) the crystals appear to be partially interlocked such that one crystal 'indents' its neighbour at a point contact.

(vi) at 3704.6m (Figures 1C and 1D) platey, probably smectitic, clays occur in the matrix pores.

Fauna and Flora

The fauna present in this interval consists of recurrent planktonic foraminifera and bivalves (especially inoceramid debris), commonly distributed benthonic rotalid foraminifera and ostracods, with sparsely distributed echinoderms and probable belemnite debris. The S.E.M. plates show abundant coccoliths (with occasional rhabdoliths) and indicate a prolific chrysophyte flora.

Diagenesis

The S.E.M. examination of samples from this interval shows markedly different textures than in the preceding interval (3693.1m-3697.4m).

(i) The crystals making up the matrix are more angular and are often clearly coccolith platelets.

(ii) The pore system appears to be more open with somewhat polyhedral pores.

(iii) The matrix crystals are evidently smaller.

These three features collectively indicate that there has been little overgrowth cementation as compared to the interval previously described. Also evident in the S.E.M. examination are the local indentured point contacts of neighbouring grains, which are taken as evidence of point welding. Similar contacts have been described by Mapstone (1975).

Petrographic analysis indicates that up to 6% (B.V.) of the rock consists of cements. These occur within foraminifera chambers and are chiefly blocky or microcrystalline calcite. The latter may form in part as a result of the complete overgrowth cementation of micritic matrix debris within foraminifera chambers.

The S.E.M. views in Figures 18B to D of the sample from 3704.35m show a foraminifera chamber which has not undergone any excessive overgrowth cementation, which indicates that the matrix within the foraminifera is less compacted than that outside. The slightly larger pore size and pore throat size may be more conducive to overgrowth cementation at horizons being supplied with carbonate saturated waters. Alternatively the calcite may have been a microcrystalline cement initially infilling a pore space. Minor amounts of clay occur in the rock matrix and along pressure solution planes (trace amounts of kaolinite and illite are recorded in the X.R.D. results). Trace amounts of euhedral quartz and pyrite occur locally within the interval.

All these diagenetic processes are envisaged as occurring in a marine phreaticdiagenetic environment.

Porosity and Permeability

Porosity; range 27.7% to 41.9% (average 33%).

Permeability; range 0.25md to 2.2md (average 0.65md).

Porosity is chiefly of matrix origin, although 3% to 14% intragranular porosity has been recorded with foraminifera chambers. Matrix pores range up to 7μm in diameter, whilst pore throat sizes are generally <1μm, hence the low permeabilities over the interval.

3705.85m-3708.01m Gap (2.25m)

INTERVAL 3708.01m-3710.35m

Lithology

This interval consists of lime mudstones and local lime wackestone. Compositionally the sediments consist of unabraded intact or fragmented pelagic foraminifera and comminuted skeletal debris in a lime mud matrix. There are traces of lamination or bedding, apparent from the layers of foraminifera. Clay is evident along pressure solution planes, whilst X.R.D. analysis indicates the presence of patchily distributed kaolinite and up to 2% illite.

Scanning Electron Microscopy

The S.E.M. characteristics of the rocks of this interval are very similar to those of interval 3702.2m to 3705.85m, ((i) to (vi) pp. 3-4).

The matrix is thus seen to consist of predominantly disaggregated coccoliths (platelets with angular crystals in no apparent orientation). The coccoliths vary in size and, presumably species. Clay material is evident at 3708.01m (Figures 22C and D) and welded contacts are apparent below 3710.05m, where the crystals appear to have undergone overgrowth cementation, hence the lower porosity value (<20%). Cementation is evident in 3710.01m (Figure 26D) where a coccolith has lost much of the platelet structure. The matrix porosity is clearly interconnected, polyhedral and the pores <3μm in size.

Fauna and Flora

The fauna of this interval consists of recurrent planktonic foraminifera and phosphatic (fish) debris, whilst benthonic rotalid foraminifera and ostracods are commonly distributed. Bivalve debris, chiefly inoceramid, is sparsely distributed. A flourishing nannoflora of coccolithophorids is evident from S.E.M. plates.

Diagenesis

Diagenetic alteration in this interval may be summarised as:

(i) Point welding of grains.

(ii) Overgrowth cementation of matrix material.

(iii) Localised grain fracture.

(iv) The development of pressure solution planes.

(v) Cementation of intragranular pores (foraminifera chambers) by microcrystalline and blocky calcite.

(vi) The growth of phosphatic micronodules.

(vii) The growth of sporadically distributed pyrite crystals.

These diagenetic alterations are unevenly distributed such that a distinct 'zone' of overgrowth cementation, which leads to significant porosity reduction, occurs below 3710.05m.

Porosity and Permeability

Porosity; range 13.0% to 37.8%, average 28.0%.

Permeability; range 0.15md to 1.54md, average 0.71md.

Porosity in this interval is chiefly of matrix type and unevenly distributed. Porosities are higher at the top of the interval (above p.4), with an average of 34.2%, whilst below this the average is 17.5%. Only four measurements were available for permeability and the low values are due to the small size of the matrix pores, pore throats and the effect of overgrowth cementation.

3710.35m-3716.05m Gap (5.7m)

UPPER HOD FORMATION

INTERVAL 3716.05m-3717.85m

Lithology

This interval consists of bioturbated lime mudstones. Compositionally the sediments consist of partially cemented, unsorted, unabraded skeletal material, including planktonic foraminifera, within a porous lime mud matrix. Cements occur within foraminiferal chambers and account for up to 6% (B.V.).

A microfracture, partially cemented by microcrystalline calcite, occurs at 3717.35m. Trace amounts of quartz, fluorite and pyrite have also been recorded from this interval.

Scanning Electron Microscopy

Scanning electron microscopy shows the following features in the samples examined:

(i) There is no apparent orientated fabric within the rock matrix.

(ii) The 'crystals' of the matrix have planar faces, indicating some overgrowth cementation.

(iii) The coccoliths present are frequently fragmented.

(iv) The sample at 3717.85m has a finer sized matrix than those above (i.e. <2μm compared to 0.7μm-6μm).

(v) The matrix pore network is polyhedral and interconnected, whilst the pores are generally smaller at 3717.85m.

Fauna and Flora

The fauna of this interval consists of recurrent planktonic foraminifera (frequent or common in abundance) and phosphatic (fish) debris, whilst benthonic rotalid foraminifera and bivalve debris occur below 3716.3m. Examination of S.E.M. plates indicates a chrysophyte flora of coccolithophorids.

Diagenesis

Cementation is the chief diagenetic process in this interval and is evident at two levels:

(i) S.E.M. examination indicates a degree of overgrowth cementation (evident from the planar matrix crystal faces).

(ii) Petrographic analysis shows cementation of foraminifera chambers (1% to 6% B.V.) by microcrystalline and locally blocky calcite. At 3717.85m a microfracture is also cemented by microcrystalline calcite.

The only other diagenetic process evident in the interval is the local precipitation of pyrite in foraminifera wall pores.

Porosity and Permeability

Porosity; range 13.2% to 31.7%, average 22.4%.

Permeability; range 0.65md to 4.16md, average 2.4md.

This thin (1.8m) interval is divisible (at 3716.4m) into a high porosity upper unit and a lower porosity lower unit. The only available permeability data are from the upper unit.

INTERVAL 3717.85m-3722.06m

Lithology

This interval consists chiefly of lime mudstones with subordinate limes wackestone. The sediments comprise unsorted, unabraded planktonic foraminifera and skeletal debris in a lime mud matrix. Minor amounts of quartz (<4%), kaolinite and phosphate are also present.

Scanning Electron Microscopy

The scanning electron microscopy undertaken on the samples from this interval indicates that these rocks have undergone varying degrees of overgrowth cementation and local dissolution.

Three matrix 'textures' are evident:

(i) Planar crystals make up the matrix with moderately good porosities e.g. 3720.01m Figure 30D, 3722.35m Figure 11D.

(ii) Matrix crystals with interlocking planar faces and coccoliths are almost completely obliterated (except in outline); low porosities; e.g. 3721.35m Figure 7D.

(iii) 'Rounded' overgrown and partially dissolved matrix crystals often with adjacent crystals apparently fused; low porosities; e.g. 3720.35m Figure 4D, 3720.7m Figure 5D.

Throughout all of these samples there is no apparent orientated fabric, as assessed by the orientation of coccoliths. The character of the microporosity is discussed elsewhere.

Fauna and Flora

The fauna of this interval consists of recurrent planktonic foraminifera and rotalid benthonic foraminifera with sparsely distributed bivalves, ostracods, echinoderms, sponge spicules and phosphatic (fish) debris.

The S.E.M. plates indicate the occurrence of a chrysophyte flora of coccolithophorids.

Diagenesis

The diagenetic process of principal interest in this interval is cementation.

Cementation occurs in three major forms:

(i) The overgrowth cementation of the matrix material.
(ii) The cementation of primary pores such as foraminifera chambers.
(iii) The cementation of microfractures or microfracture networks.

The overgrowth cementation of the matrix material, as stated previously, is envisaged as a marine phreatic process (Neugebauer, 1974; Scholle, 1974; Mapstone, 1975; Hardman and Kennedy, 1980), perhaps developing at hardgrounds or incipient hardgrounds. The cements produce planar faces on matrix 'crystals' and result in an interlocked texture. A rounded matrix, recorded in the S.E.M. notes, is taken as evidence of dissolution of the overgrown matrix 'rounding-off' the planar crystal form.

The cementation of primary, chiefly intragranular, pores is by microcrystalline, and to a lesser extent blocky, calcite. This is again envisaged as a marine phreatic process and may occur simultaneously with the overgrowth cementation of the matrix.

Post-dating these cementation phases was a phase of fracturing or microfracturing of the rocks. Networks of varying complexity cut the rock and the foraminifera with cemented chambers. Subsequent to the fracturing was another cementation episode infilling the microfractures with blocky or more frequently microcrystalline calcite. Cementation is occasionally imcomplete and fracture porosity remains.

In some instances traces of, or occasionally up to 1%, kaolinite occur as a late stage diagenetic mineral. A micronodule of phosphate occurs at 3720.01m and has ghost grains indicating its replacement origin.

Porosity and Permeability

The porosity of this interval is chiefly of matrix origin and its distribution within the interval falls into two distinct units:

(i) 3717.85m-3720.35m; range 4.0% to 9.03%, average 5.6%.

(ii) 3720.35m-3722.06m; range 10.07% to 23.09%, average 15.02%.

Measured permeabilities are low as a consequence of the small size of the pore throats, with values up to 0.58md.

INTERVAL 3722.06m-3728.05m

Lithology

The rocks of this interval consist chiefly of lime mudstones with subordinate wackestones and packstones. Compositionally they are composed of unabraded and unsorted planktonic foraminifera and up to 18% skeletal debris in a lime mud matrix. Minor or trace amounts of kaolinite (in fracture and foraminifera chambers) and quartz occur in the interval.

Residual hydrocarbons occur at 3725.05m in foraminifera chambers and along fractures.

Scanning Electron Microscopy

The scanning electron micrographs of samples from this interval show the following features:

(i) The samples show a marked increase in the abundance of coccoliths and the presence of occasional, well defined rhabdoliths (still attached to its coccolith - 3737.0m Figures 20C and 20D).

(ii) The crystals making up the matrix often have planar faces and have undergone some overgrowth cementation.

(iii) Locally (2735.05m) overgrowth cementation affects coccoliths.

(iv) There is no apparent orientated fabric within the matrix.

Diagenesis

The diagenetic process of primary importance in this interval is cementation.

Cementation occurs chiefly in two modes:

(i) Overgrowth cementation of micritic matrix crystals.

(ii) Cementation of primary pores by microcrystalline and blocky calcite.

The overgrowth cementation of the matrix is evident from the planar crystal faces. Cementation of the primary pores by calcite (microcrystalline and blocky) accounts for between 4% and 30% (B.V.) of the rock. The latter figure is somewhat atypical as it represents a single packstone sample. In general cements range from 4% to 12% (B.V.). Both modes of cementation are envisaged as marine phreatic as in previous instances (p. 11).

Post-dating the cementation phase was a phase of compaction producing pressure solution planes and clay-lined microstylolites e.g. at 3726.06m. Clay also occurs in foraminifera chambers and locally occurs as a cement in some microfractures.

Minor diagenetic effects include the growth of trace amounts of euhedral, authigenic quartz (e.g. 3725.01m) and the local development of fluorite (at 3726.06m).

The last 'diagenetic' stage in the sequence is the impregnation of the rocks with hydrocarbon, some of which still occurs in microfractures.

3728.05m-3733.2m Gap (4.7m).

INTERVAL 3733.2m-3739.35m

Lithology

This interval consists of lime mudstones with subordinate lime wackestones. Compositionally the rocks are composed of unsorted, unabraded planktonic foraminifera and skeletal debris (2% to 17%) in a lime mud matrix. The sediments are bioturbated but occasional laminae still remain defined by foraminifera. Pressure solution planes with a clay lining are present in the interval. Kaolinite, smectite, pyrite and dolomite occur in minor or trace amounts in these rocks.

Scanning Electron Microscopy

The S.E.M. examination showed the following features:

(i) There is no apparent orientated fabric within the matrix.
(ii) Locally, coccoliths show slight overgrowth cementation and some matrix crystals show well defined planar faces (evidence of overgrowth cementation).
(iii) Clays are evident in the matrix throughout most of the interval as wispy or platy minerals in the matrix pore space.
(iv) Coccoliths are abundant in the samples examined.

Fauna and Flora

The fauna of this interval consists of recurrent planktonic foraminifera (frequent in abundance) with sparsely distributed bivalves, sponge spicules, phosphatic (fish) debris, rotalid benthonic foraminifera, textularids and ostracods. The S.E.M. examination indicates the presence of a thriving chrysophyte population producing the coccoliths evident as plates.

Diagenesis

As in the previous intervals the diagenetic process of major importance is cementation of both matrix crystals (overgrowth cementation) and of intragranular (foraminifera chambers) pores, the latter by microcrystalline and blocky calcite. The cementation is envisaged as a marine phreatic process occurring relatively early in the diagenetic history.

Evidence of pressure solution in the sequence is seen where clay-lined microstylolites occur locally.

The minor diagenetic processes are similar to those described for previous intervals with euhedral, authigenic quartz crystals and kaolinite infilling foraminifera chambers. A mineral of note, although sparsely distributed in this interval, is single-crystal dolomite which occurs in trace amounts.

Porosity and Permeability

Porosity; range 27.07% to 38.04%, average 32.07%.

Permeability; range 0.24md to 1.00md, average 0.5md.

Porosity in this interval is chiefly of matrix type and the small size of the pores and pore throats results in the low permeability values.

CHAPTER 3

DEPOSITIONAL HISTORY

Introduction

The biostratigraphy of the 2/11-6 well has been described in RRI Report No. 2788P/A. Stratigraphically the intervals examined in this report belong to the Tor and Upper Hod Formations of the Chalk Group (Coniacian - Turonian to early Maastrichtian). Unconformities have been defined at log depths 3690m and 3716m at the top and the base of the Tor Formation (respectively). It should be noted that the study is primarily based on thin sections and S.E.M.s, no cores having been examined.

North Sea Chalk sediments have been described as essentially micro-coquinas of coccoliths and planktonic foraminifera (Hancock, 1975). Much of the matrix 'crystal' material originated as disaggregated coccoliths or rhabdoliths. Hardman and Kennedy (1980) have noted that the amount of clay present in the Hod and Tor Formations gradually decreases upwell. It is, primarily, variations of the coccolith, planktonic foraminifera and clay content, and to a lesser extent the subsidiary bioclasts, which cause the variations in the initial sediments of the sequence examined.

The depositional history of the sequence examined may be divided into three phases:

(i) Deposition of the pelagic sediments of the Upper Hod Formation.
(ii) Development of the Hod/Tor unconformity.
(iii) Deposition of the pelagic sediments of the Tor Formation.

Upper Hod Formation

The sediments of this formation are typically lime mudstones with sporadic wackestones and packstone. Burrows are evident from the thin sections towards the top of the Upper Hod Formation, whilst lamination (evident by concentrations of foraminifera) occurs towards the base of the sequence. It is therefore suggested that a more active infauna occurred later in Upper Hod times. This in turn is taken to indicate that shallower and more nutrient-rich conditions progressively developed. The abundance of planktonic foraminifera appears to increase from the base of the sequence to 3726.06m and decrease slightly towards the top of the Upper Hod Formation. There is, thus, an apparent peak in productivity around this time. The coccolith material in the S.E.M. figures shows plates of varying abundance and varying quality of preservation. These features may be a reflection, at least in part, of the degree of bioturbation of the sediments (as the coccoliths are modified on passing through the alimentary canal of infaunal organisms). Diagenesis has also modified the coccoliths present as they are less clearly seen in the well cemented areas (i.e. areas of intense overgrowth cementation). Palaeoecological analysis (see Enclosure 2) indicates that benthonic foraminifera become more important towards the top of the interval examined. These factors together are taken to indicate an overall shallowing of conditions during the Upper Hod Formation times, from deep to shallow inner shelf.

The Upper Hod/Tor Unconformity

An unconformity or hiatus is interpreted at the top of the Upper Hod Formation (RRI Report No. 2788P/A) in the 2/11-6 well. A Globotruncana marginata/Radiolaria - Globotruncana Assemblage (Coniacian - Turonian) occurs at the top of the Hod, whilst the base of the Tor is occupied by a Tritaxia dubia - ?Stensioina assemblage (Campanian - ?Santonian). It is, therefore, apparent that much of the Santonian stage is missing at this hiatus. The presence of the hiatus/unconformity is important as it coincides with the top of a dense/low porosity zone which probably formed as a sequence of multiple hardgrounds. Submarine erosion has been described at the same horizon in the Valhall Field (Hardman and Kennedy, 1980), and the Hod example is considered to be of the same origin. It should, however, be noted that no cores were examined in the course of this project and the unconformity was not examined.

Tor Formation

The deposition of the Tor Formation show the return of pelagic sedimentation of coccoliths, coccolith debris and planktonic foraminifera. Texturally the sediments consist of mudstones with occasional wackestones towards the base. It is notable that the predominant fauna is slightly different in the Tor Formation (compared to the Upper Hod Formation) as bivalve debris (chiefly inoceramid) rotalid foraminifera and, towards the base of the formation phosphatic (fish) debris, become recurrent. The presence of recurring inoceramid debris suggests conditions with sufficient nutrients for these filter feeders. No small scale sedimentary structures are evident in the thin sections examined except at 3704.06m where thin laminae bifurcate and merge with 'wedges' or 'elliptical' sediment packets between, suggesting sediment ripples. The paucity of structures may be taken to indicate complete reworking and homogenisation of the sediments. Environmentally the Tor Formation appears to have been deposited in shallower water conditions than the Hod Formation but nonetheless in a marine inner shelf environment.

In summary, the sequence examined was deposited in a marine inner to outer shelf environment under regressive conditions with a hiatus or unconformity developing during the Santonian.

CHAPTER 4

DIAGENETIC HISTORY

The diagenetic history of carbonate sequences often begins at or about the time of deposition. The diagenetic sequence interpreted for the samples examined is listed below and then described in more detail.

1. Diagenetic History - Summary

(i) Overgrowth cementation of matrix 'crystals'.

(ii) Cementation of foraminifera chambers by microcrystalline and blocky calcite.

(iii) Local dissolution of overgrown matrix.

(iv) Fracturing/microfracturing.

(v) Cementation of fractures/microfractures by blocky and microcrystalline calcite.

(vi) The leaching of grains to produce mouldic pores.

(vii) The cementation of fractures and foraminifera chambers by clay minerals, especially kaolinite.

(viii) The development of pressure solution planes.

2. Diagenetic History - Discussion

The samples examined from the 2/11-6 well show varying degrees of overgrowth cementation, as seen in the scanning electron micrographs. Fabrics showing some degree of cementation occur throughout the sequence. Beneath the unconformities or hiatuses described in RRI Report No. 2788P/A overgrowth cementation is pronounced. Beneath the Upper Hod/Tor hiatus, in particular, the porosity and permeability are markedly reduced. It has been noted by various authors that chalk is a particularly stable sediment, consisting almost wholly of low magnesium calcite (Hancock, 1975; Hancock and Scholle, 1975; Hardman and Kennedy, 1980). Hardgrounds are, however, developed in the chalk and are of marine phreatic origin, developing at the sediment surface or around Thalassinoide burrow systems. It is envisaged that the zones of high overgrowth cementation in the 2/11-6 sequence developed early in the diagenetic history in a similar fashion to hardgrounds.

The cemented layers in 2/11-6 (which are several metres thick) occasionallyinclude more porous horizons e.g. 3722.35m. These are taken to indicate that the thick units developed as 'multiple-hardground' structures. The effect of this cementation on the petrophysical characteristics of the rock is described in Chapter 5.

In summary, the process of overgrowth cementation reduces both porosity and permeability, especially below the Upper Hod/Tor hiatus (3716m).

Cementation of larger pores, notably foraminiferal chambers, has also taken place in the sequence examined. It is, however, unevenly distributed in the sequence (see Enclosure 1). The cements encountered may be either blocky or microcrystalline calcite. The S.E.M. plates occasionally show matrix material within foraminifera chambers which is less compressed and cemented than outside of these chambers. The microcrystalline cements in foraminifera chambers may be primary precipitates or develop as an extreme such as overgrowth cementation in a porous region. Neugebauer (1974) has described how foraminifera are more susceptible to cementation than coccoliths and the primary precipitate concept is favoured.

In the areas with matrix material heavily overgrown by calcite cements, the surface expression in S.E.M examination is usually rounded. As these rounded faces occur at pore boundaries and overgrowth cementation of lime mud usually produces planar faces, it is envisaged that the rounded appearance is due to partial dissolution of the cement. This is also evident on some coccoliths where the platelets show a rounded appearance. It is therefore clear that a period of solution followed this phase of overgrowth cementation.

In the thin sections examined there is evidence of a phase of fracturing and/or microfracturing with a subsequent phase of cementation. The cements are either blocky or microcrystalline calcite and the controlling factor on cement type is the size of the fracture pore. Blocky calcites occur in the larger 'fractures' (>0.05mm) whereas in the smaller 'microfractures' (<0.05mm) microcrystalline calcites develop (Plate 4). The distribution of the fractures/microfractures is limited in the sequence to the 'dense' zone beneath the Tor/Hod unconformity. This is, however, regarded as an indication of the competence of the unit (as compared to the high porosity limestones below or above) as the uncemented chalk would deform rather than fracture.

Despite the highly stable mineralogical nature of the chalk sediments, the samples examined show leached mouldic pores below 3734.01m, with an increase in abundance towards the base of the well (to 3% B.V.). The shape of the pores suggests that sponge spicules are the major grains dissolved and these may well have been of a siliceous composition and hence unstable in a carbonate sequence.

X-ray diffraction techniques and petrographic analyses indicate that clay minerals occur as cements in both foraminifera chambers and along part open fractures. Kaolinite and to a lesser extent smectites are the chief minerals involved.

Kaolinite and smectite are authigenic and require alkaline conditions. They formed in a deep phreatic phase of diagenesis, clearly after the phase of fracturing. Smectite requires alkaline conditions, whilst kaolinite requires acid conditions to develop. Kaolinite is most often observed in fracture pores and is envisaged as a later clay phase only affecting fractures. It has already been noted that chalk is a chemically stable material and the paucity of carbonate in solution may have allowed the local development of acid conditions in fractures, especially as in the dense zones (where fractures are most common) the permeability is so low.

The section examined often shows indications of pressure solution taking place in the rocks leading to the development of solution planes. Such planes develop at considerable pressures usually from the effects of overburden. They are usually microstylolitic (<1cm amplitude) in the section examined and are often lined with insoluble residues left after the dissolution of the rock mass between the plane faces. It is noticeable that cementation of foraminiferal chambers is often increased in the vicinity of these planes, probably as a result of the local mobilisation of the dissolved carbonate. Since cores were not examined it is not known whether higher amplitude stylolites occur in the section or whether the distribution of stylolites seen in thin section is typical of the core.

The diagenetic history of the sequence examined thus extends from the early marine diagenetic processes to deep burial processes. The various effects have been both beneficial and detrimental to the reservoir quality.

CHAPTER 5

RESERVOIR CHARACTERISTICS

The sequence of the Tor and Upper Hod Formations examined can be divided into four zones of differing reservoir quality. The reservoir characteristics of the rocks are the net result of the original depositional characteristics and their diagenetic history. In these chalk (lime mudstone) lithologies the nannofabric is the primary control on the petrophysical characteristics. Details of the lithology, diagenesis and fauna/flora of these zones have been described in detail in Chapter 2. In this section, the most important of these characteristics, with regard to reservoir quality, are discussed. Porosity - permeability cross-plots and histograms for each zone are presented as Figures 3 to 6, whilst photomicrographs showing variation in sediment character and diagenesis can be found at the back of the report.

Reservoir Zone I 3693.1m-3697.4m (Tor Formation)

Porosity; range 24.2% to 34.6%, average 31.1%

Permeability; range 0.29md to 1.76md, (3 measurements only)

The nannofabric of this zone is porous, often with both overgrowth cementation and some subsequent dissolution. Porosity is chiefly of matrix-type (1μm-4μm) with up to 8% intra-foraminifera porosity. The matrix pore shapes are predominantly irregular polyhedral (with curved walls) and interconnected. There is locally up to 5% intragranular cement in foraminifera chambers, slightly reducing the original porosity.

Reservoir Zone II 3697.4m to 3716.05m (Tor Formation)

Porosity; range 23.8% to 42.0%, average 35.1%

Permeability; range 0.25md to 3.61md, average 0.8md

The nannofabric of this zone is porous with a minor amount of overgrowth cementation and local point contact indentations. The pores are irregular, polyhedral, interconnected and range up to 3μm in size. Occasional clay minerals, such as smectites, are present partially occluding the pore network. Cements (microcrystalline and blocky calcite) in intragranular pores are a constant feature of the unit and contribute up to 8% of the rock.

Reservoir units I and II differ on the nannofabric and consequently on the lower average porosity of unit I.

Reservoir Zone III 3716.05m-3723.1m (Upper Hod Formation)

Porosity; range 4.1% to 23.9%, average 10.2%

Permeability; range 0.001md to 0.58md, average 0.32md

The rocks of this interval show a high degree of overgrowth cementation and a minor amount of dissolution resulting in a tight fabric. The degree of cementation varies over the interval and towards the top and base of the unit the porosities are considerably higher. The pores range in shape from polyhedral to rounded, and in size up to 2µm. The matrix crystals are often interlocked and indented. A phase of fracturing (and microfracturing) occurred after cementation and the fractures have subsequently been cemented by blocky and microcrystalline calcite. Kaolinite is locally developed in the unit but only in minor (<3%) amounts.

Reservoir Zone IV 3723.1m-3739.35m (Upper Hod Formation)

Porosity; range 23.3% to 38.4%, average 30.1%

Permeability; range 0.24md to 1.6md, average 0.58md

The nannofabric of this unit is porous with local evidence of grain welding (3726.1m, Figure 18D). The pore system is of an open matrix type with only minor overgrowth cementation. The pore network is polyhedral, interconnected, with pores up to 4µm, although larger intra-foraminiferal pores contribute up to 9% (B.V.). Up to 30% (B.V.) intragranular cements (chiefly blocky calcite) have been recorded, but <10% is more common. Clay minerals, kaolinite and smectite, are recorded from the pore network of the rocks and increase in abundance towards the base of the sequence.

SUMMARY

The variation in porosity and permeability is due to the development of multiple hardgrounds with a higher degree of overgrowth cementation, and to the local cementation of intra-foraminiferal pores. The hardgrounds correspond to the hiatuses at the top and base of the Tor Formation.

CHAPTER 6

REFERENCES

HANCOCK, J.M. 1975. The Petrology of the Chalk. Proc. Geol. Ass., 86, pp. 499-535.

HANCOCK, J.M. and SCHOLLE, P.A. 1975. Chalk of the North Sea In. A.W. Woodland (Edt.) Petroleum and the Continental Shelf of Northwest Europe. I Geology. Applied Science Publishers pp. 413-427.

HARDMAN, R.F.P. and KENNEDY, W.J. 1980. Chalk reservoirs of the Hod Fields, Norway, In. The Sedimentation of the North Sea Reservoir Rocks, Norsk Petroleumsforening (NPF) 31p.

MAPSTONE, N.B. 1975. Diagenetic history of a North Sea Chalk. Sedimentology, 22, pp. 601-603.

NEUGEBAUER, J. 1974. Some aspects of cementation in chalk. In. K.J. Hsu and H.C. Jenkyns (Edts): Pelagic Sediments: on land and under the sea. Spec. Publ. Int. Ass. Sediment., 1, pp.149-176.

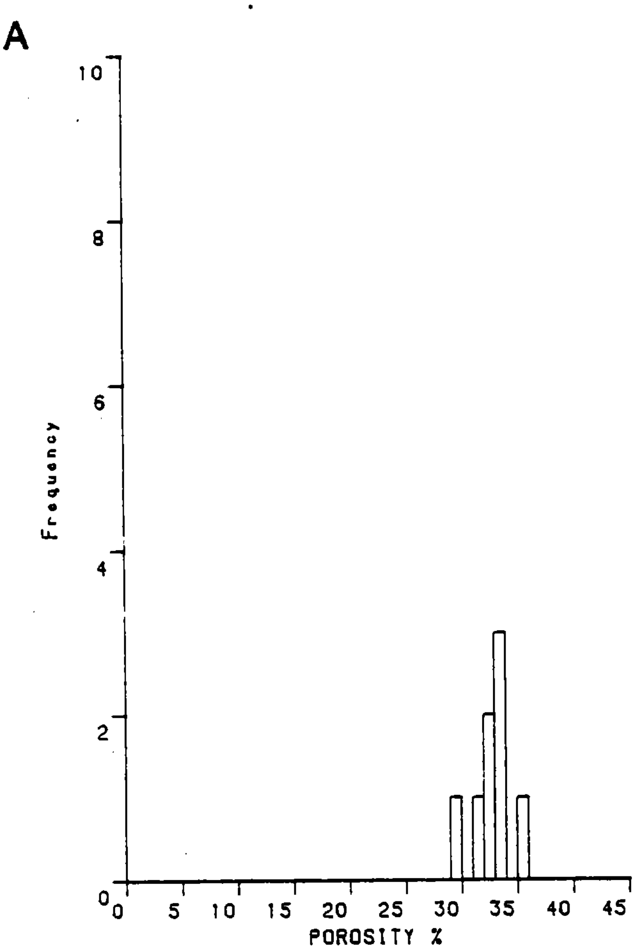
SCHOLLE, P.A. 1974. Diagenesis of Upper Cretaceous chalks from England, Northern Ireland, and the North Sea In. K.J. Hsu. and H.C. Jenkyns (Edts) : Pelagic Sediments : on land and under the sea. Spec. Publ. Int. Ass. Sediment., 1., pp. 177-210.

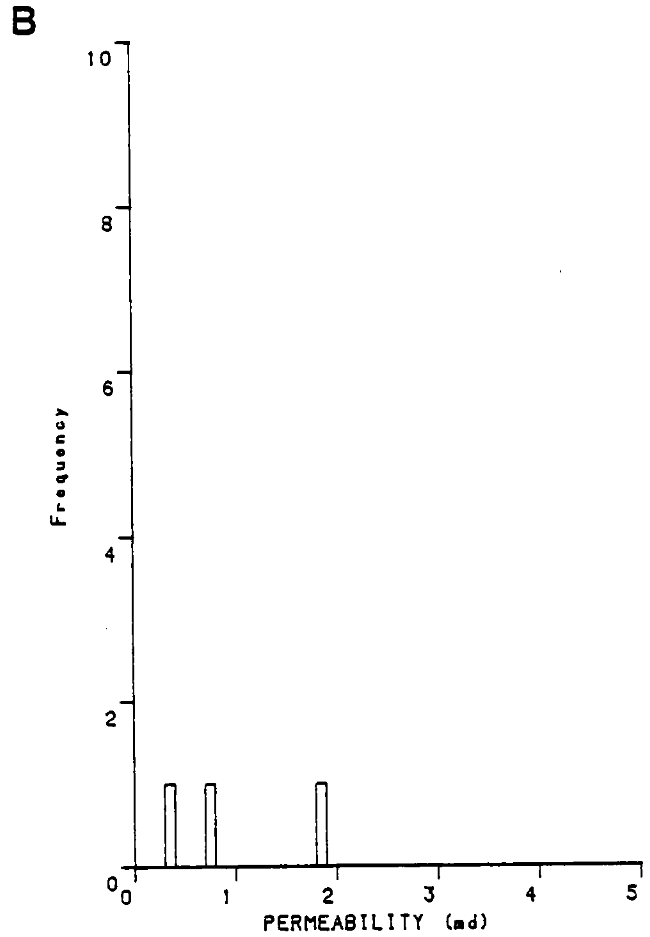
ROBERTSON RESEARCH INTERNATIONAL LIMITED. Confidential Report:
CHURCH, J.W., CONNELL, P.G., DUXBURY, N., FRAME, P., MILES, N.H. and MORTIMER, C.P., Amoco Norway 2/11-6 Well and 2/11-6 Sidetrack: Biostratigraphy of the intervals 180m-3970m T.D. and 3607.5m-4075m T.D. Report No. 2788P/A.

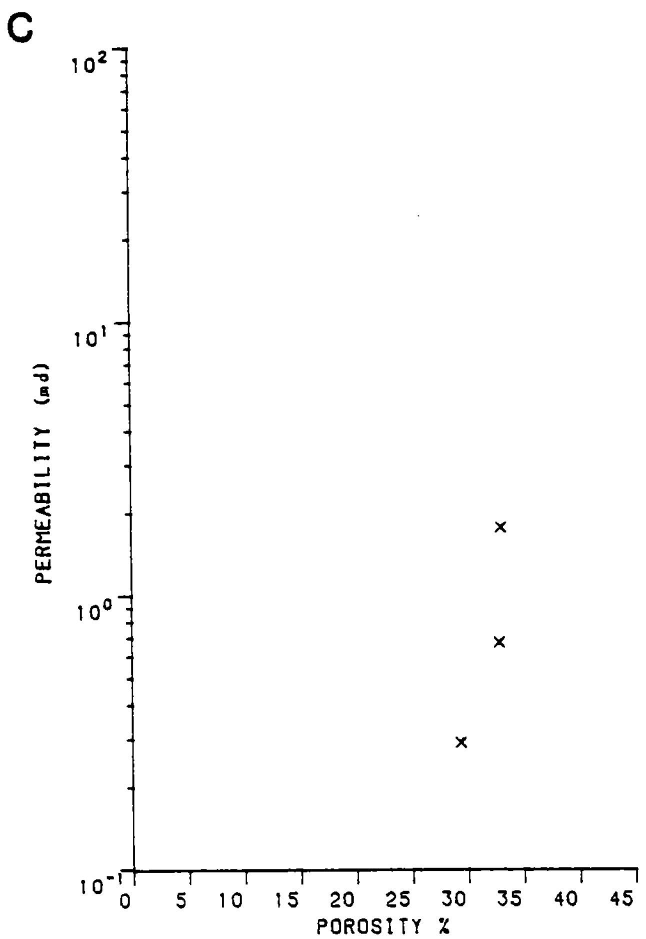
FIGURES 3 TO 6

Frequency distributions of Core Porosity (A), Core Permeability (B) and Porosity v Permeability cross-plots

FIGURE 3 : RESERVOIR ZONE I
FIGURE 4 : RESERVOIR ZONE II
FIGURE 5 : RESERVOIR ZONE III
FIGURE 6 : RESERVOIR ZONE IV







RESERVOIR ZONE : I

A = Frequency Distribution of Core Porosity

B = Frequency Distribution of Core Permeability

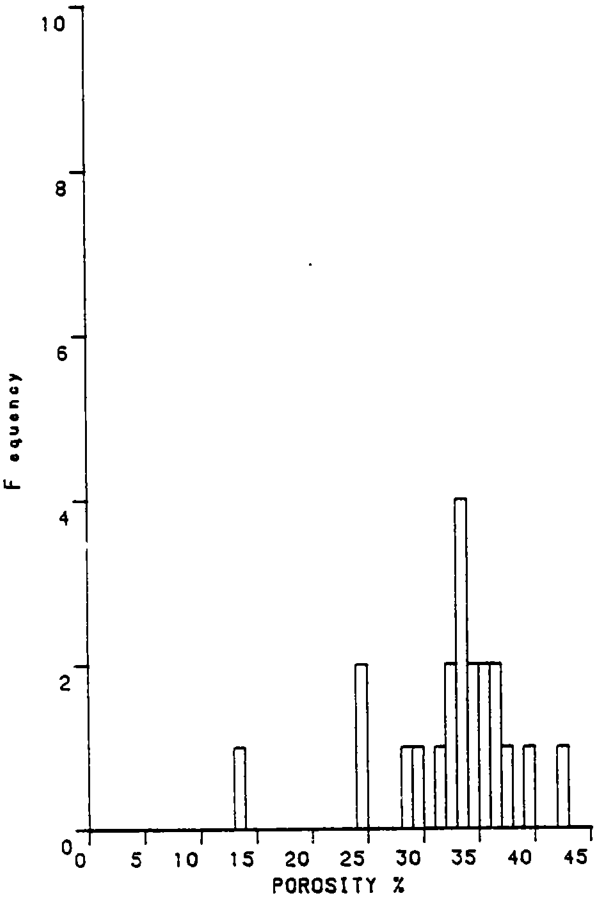
C = Porosity V Permeability cross-plot

Statistics :

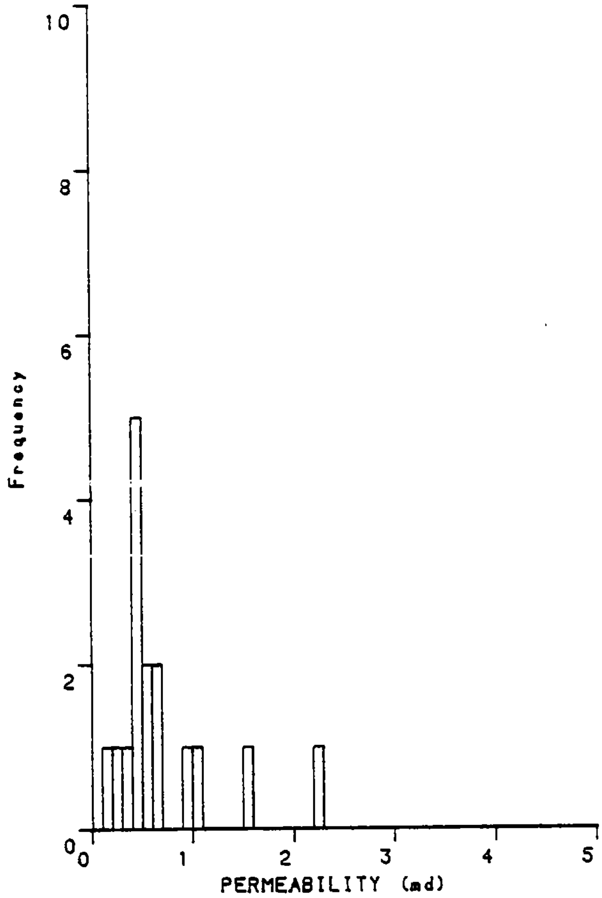
Øm	31.80	Km	2.08
Østd dev	0.91	Kstd dev	0.76

Correlation Coefficient r = 0.86955

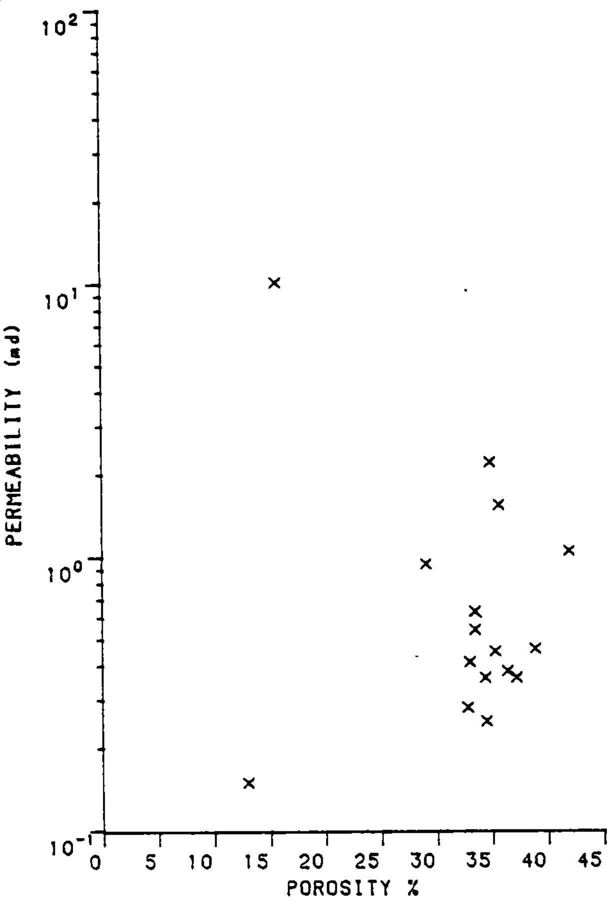
A



B



C



RESERVOIR ZONE : II

A = Frequency Distribution of Core Porosity

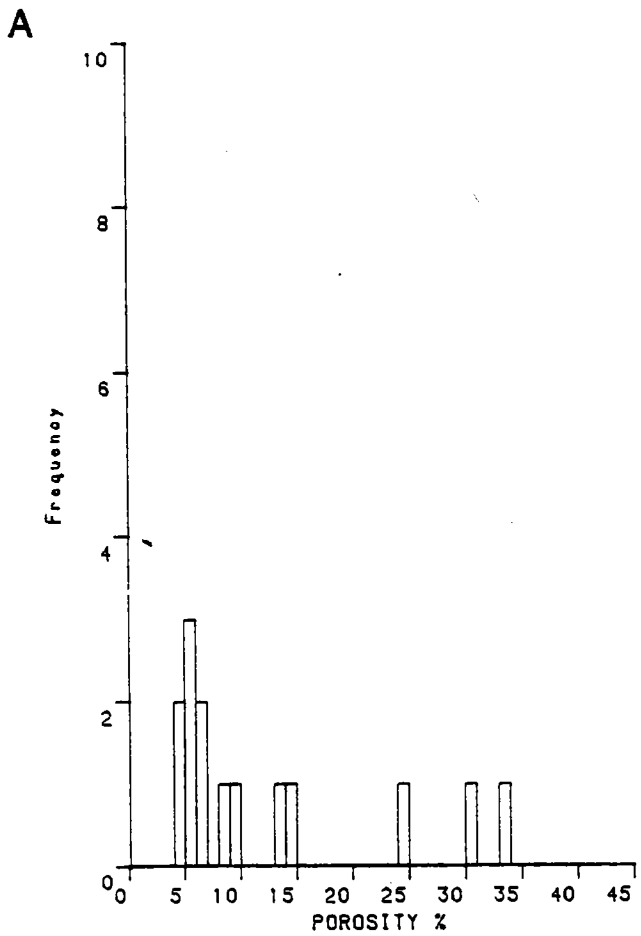
B = Frequency Distribution of Core Permeability

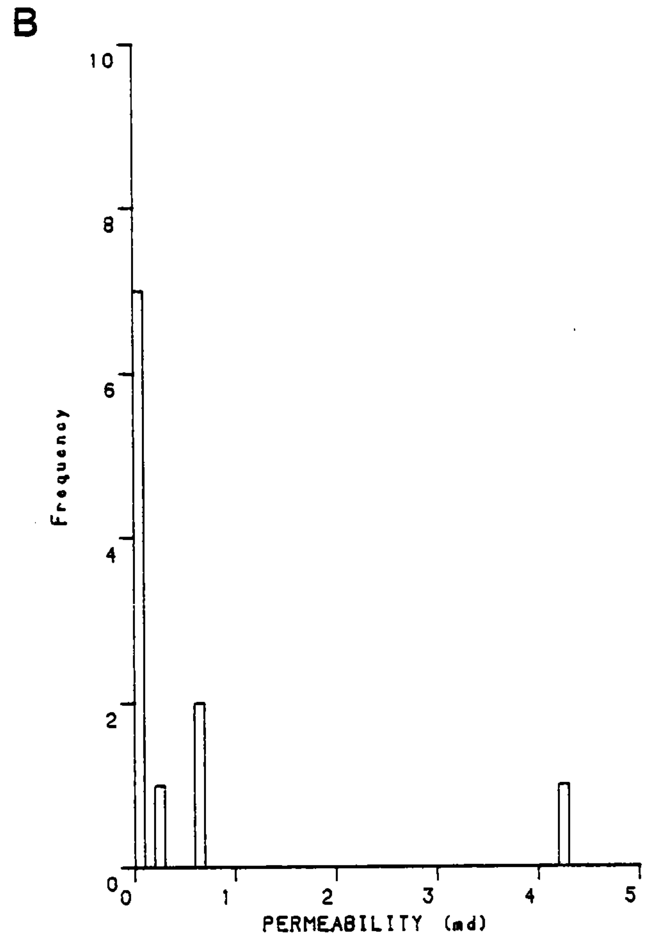
C = Porosity V Permeability cross-plot

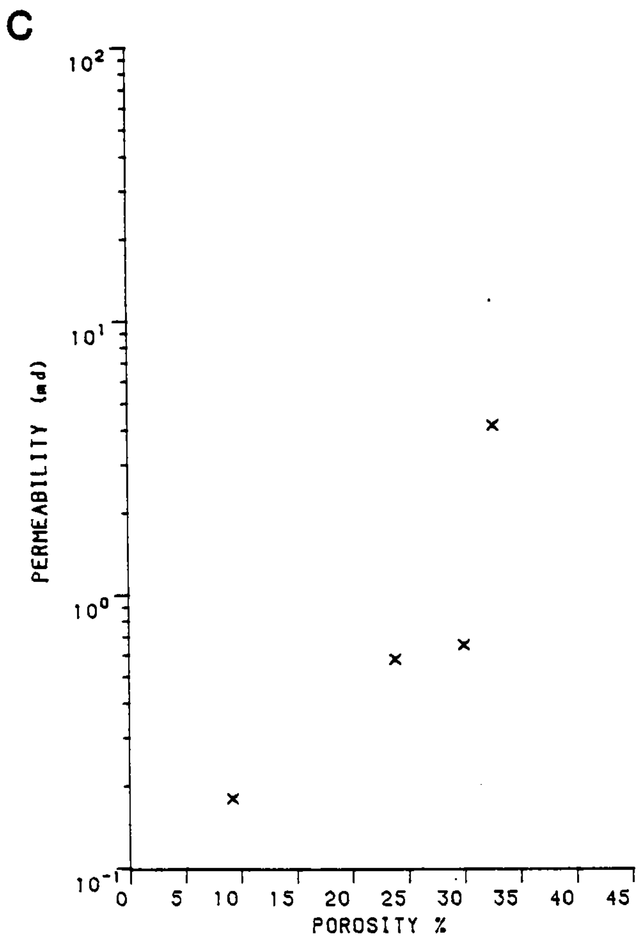
Statistics :

Øm	32.49	Km	1.26
Østd dev	7.64	Kstd dev	2.42

Correlation Coefficient r = 0.17550







<u>RESERVOIR ZONE : III</u>

A = Frequency Distribution of Core Porosity

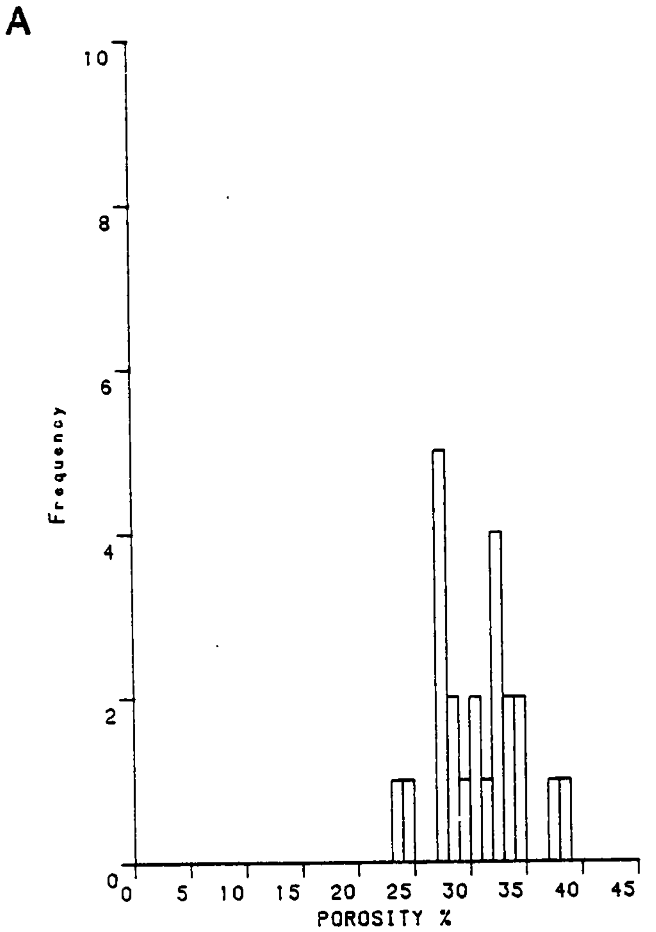
B = Frequency Distribution of Core Permeability

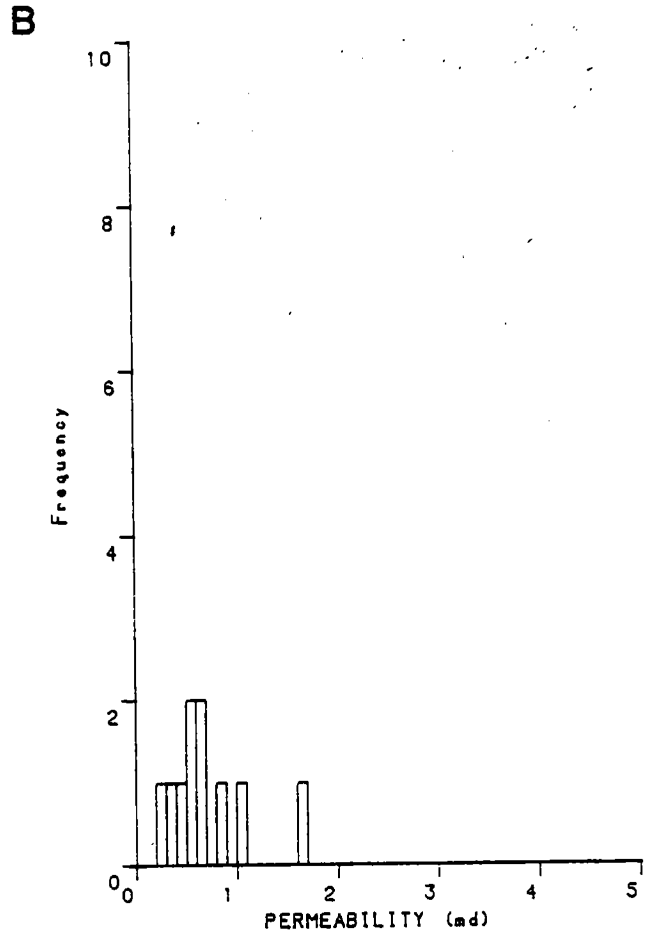
C = Porosity V Permeability cross-plot

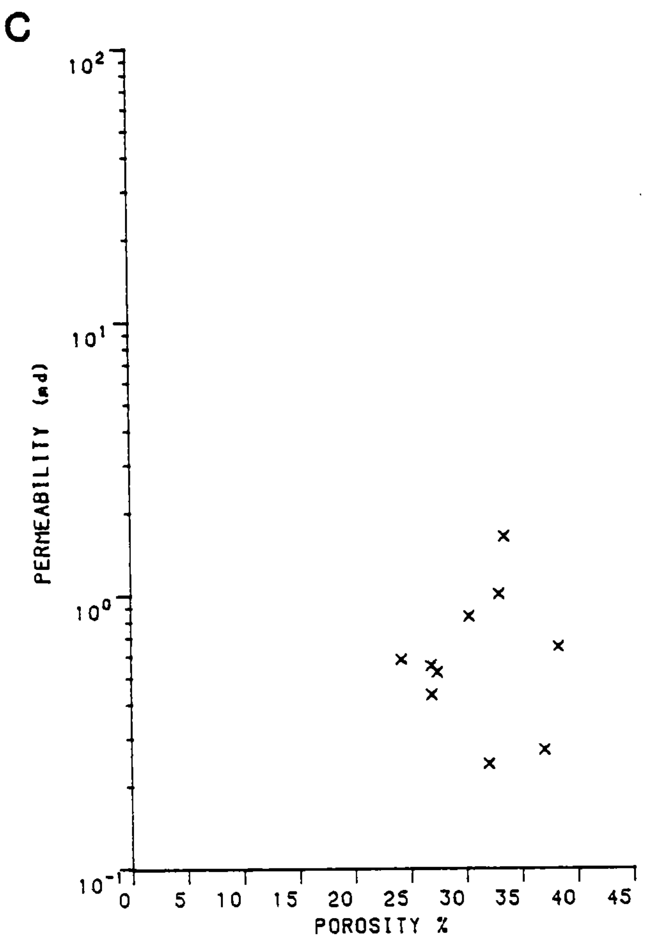
<u>Statistics :</u>

Øm	23.98	Km	1.39
Østd dev	10.45	Kstd dev	1.86

Correlation Coefficient r = 0.86100







RESERVOIR ZONE : IV

A = Frequency Distribution of Core Porosity

B = Frequency Distribution of Core Permeability

C = Porosity V Permeability cross-plot

Statistics :

Øm	31.05	Km	0.67
Østd dev	4.64	Kstd dev	0.41

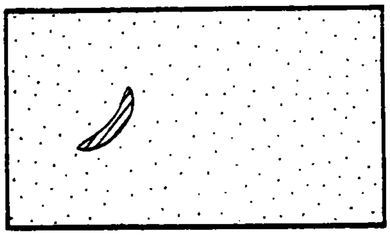
Correlation Coefficient r = 0.02043

APPENDIX 1

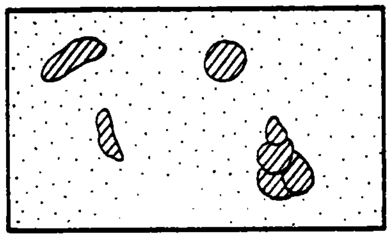
DUNHAM CLASSIFICATION

DUNHAM CLASSIFICATION
(Based on Depositional Texture)

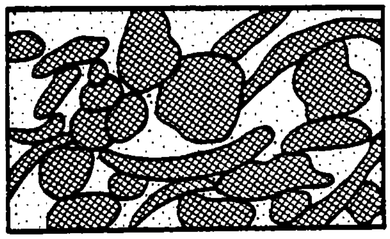
MUDSTONE
(mud-supported, less than 10% grains)



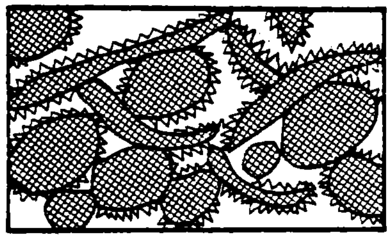
WACKESTONE
(mud-supported, more than 10% grains)



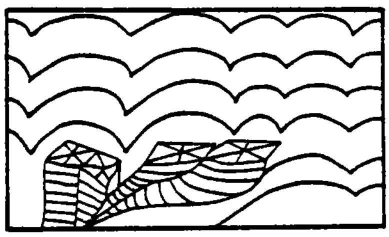
PACKSTONE
(grain-supported,
but contains interstitial mud matrix)



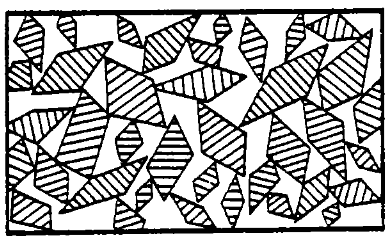
GRAINSTONE
(grain-supported, lacks interstitial mud matrix)



BOUNDSTONE
(original components bound together)



CRYSTALLINE CARBONATE
(e.g. DOLOMITE)
(depositional texture destroyed by diagenesis)

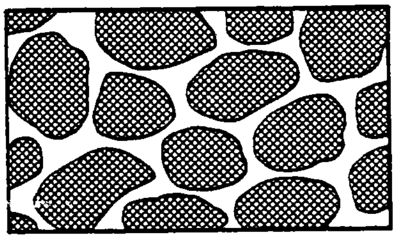


APPENDIX 2

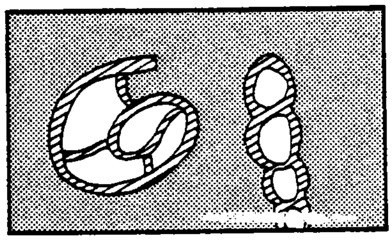
POROSITY TYPES

COMMON POROSITY TYPES

PRIMARY

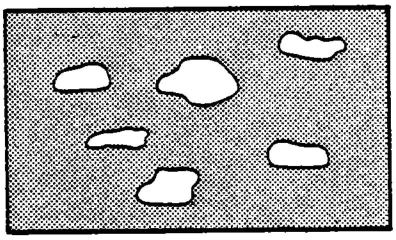


INTERGRANULAR

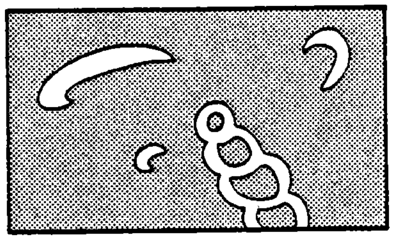


INTRAGRANULAR

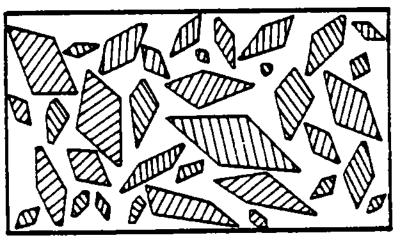
SECONDARY



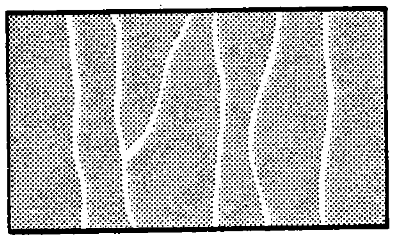
VUGULAR



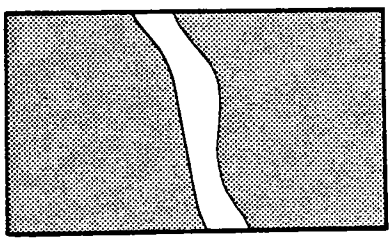
MOULDIC



INTERCRYSTALLINE



FRACTURE

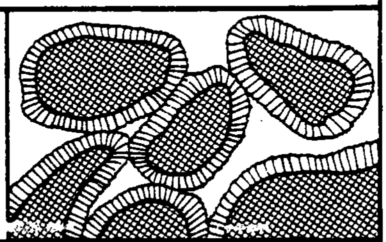
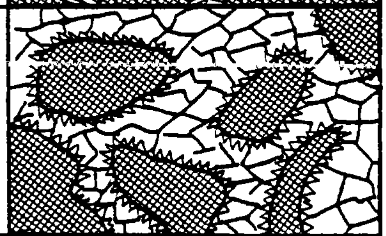
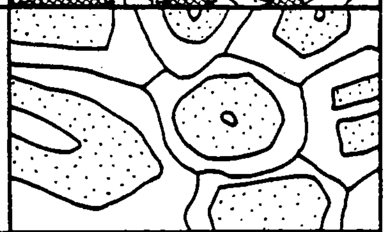
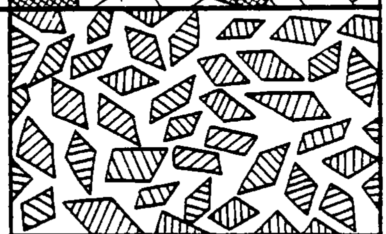
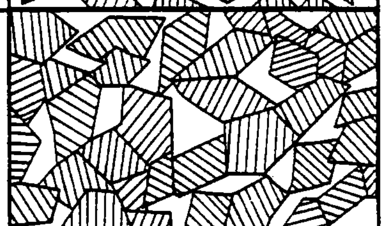
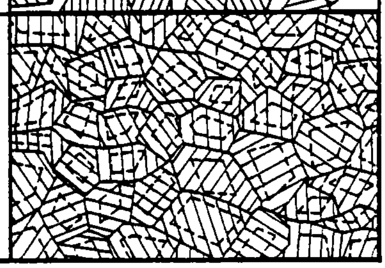


CHANNEL

APPENDIX 3

DIAGENETIC FABRICS

DIAGENETIC FABRICS

PROCESS	FABRIC	
CEMENTATION	DRUSY CEMENT	
	BLOCKY CEMENT	
	SYNTAXIAL RIM CEMENT	
	POIKILOTOPIC CEMENT	
DOLOMITISATION	IDIOTOPIC TEXTURE	
	HYPIDIOTOPIC TEXTURE	
	XENOTOPIC TEXTURE	

APPENDIX 4

NANNOFOSSIL TERMINOLOGY

APPENDIX

NANNOFOSSIL TERMINOLOGY

CHRYSOPHYTE	: Algae of the Division Chrysophyta which include diatoms and coccolithophorids.
COCCOLITH	: A single plate (composed of platelets) which forms the skeleton of certain chrysophyte algae.
COCCOLITHOPHORID	: The chrysophyte algae which produce coccoliths
RHABDOLITH	: Solid spines attached to the basal disc of certain coccoliths.

ROBERTSON RESEARCH INTERNATIONAL LIMITED

STANDARD LEGEND

CONTENTS

LITHOLOGIES

- Clay
- Shale/mudstone
- Siltstone
- Sand/sandstone, very fine to medium grained
- Sand/sandstone, coarse grained to granules
- Conglomerate (with sand matrix)
- Conglomerate (without sand matrix)
- Coal/lignite
- Breccia
- Limestone (undifferentiated)
- Dolomitic limestone
- Calcareous dolomite
- Dolomite
- Lime mudstone (Dunham Classification)
- Wackestone (Dunham Classification)
- Packstone (Dunham Classification)
- Grainstone (Dunham Classification)
- Boundstone (Dunham Classification)
- Recrystallised limestone
- Chalk
- Chert
- Anhydrite
- Salt (halite)
- Potassium salts
- Veins
- Concretions/nodules
- Igneous rocks, undifferentiated
- Basement, undifferentiated
- Granite

Streaks or lenses

- Shale
- Siltstone
- Sandstone
- Limestone
- Dolomite

Qualifiers

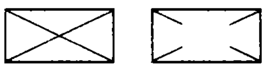
- Argillaceous
- Silty/sandy
- Pebbly
- Carbonaceous
- Calcareous
- Dolomitic
- Red sediments

LITHOLOGIES (Continued)

Accessories

Anhydrite	A
Chert/chalcedony	Ch
Calcite	C
Dolomite	D
Ironstone (ferruginous)	Fe
Glauconite	Gl
Kaolinite	K
Mica	m
Phosphate	Ph
Quartz	Q
Pyrite	Py
Siderite/sphaerosiderite	S
Silica	Si

Other symbols

Sample gap 

Lost circulation material	lcm
Cement	cmt
Turbo drilling or diamond bit drilling (Samples unsuitable for good stratigraphic analysis)	tu
Casing point	◢
Core	|
Sidewall core	◄
Sidewall core (no recovery)	◁

BIOSTRATIGRAPHIC SYMBOLS

Fossil Abundances	Present	○
	Common	●
	Abundant	■
Diagnostic forms		*
Caved forms		C
Reworked forms		R
Incoming of		↱
Outgoing of		↳
Unconformity/stratigraphic hiatus		∿∿∿
Late		LT., lt.
Middle		M., m.
Early		EY., ey.

ROBERTSON RESEARCH

FOSSIL TYPES

- Algae
- Ammonites
- Belemnites
- Brachiopods
- Bryozoa
- Calpionellids
- Charophytes
- Corals and stromatoporoids
- Crinoids
- Echinoids
- Fish scales
- Fish remains
- Foraminifera, small benthonic
- Foraminifera, larger
- Foraminifera, planktonic
- Fossils in general
- Gastropods
- Pelecypods (bivalves)
- Oligosteginids/Calcispheres
- Ostracods
- Radiolaria
- Rudists
- Serpulids
- Spicules

Plant material

- Roots
- Wood fragments – large branches, trunks, etc.
- Wood fragments – small branches, twigs, etc.
- Leaves
- Indeterminate plant debris

GRAIN TYPES

- Angular particle
- Rounded particle
- Aggregate particle
- Coated particle
- Oolith
- Peloid
- Fossils in general
- Bioclastic debris
- Fossils, abraded/rounded
- Relict indeterminate grains
- Mudflakes
- Onkoids

SEDIMENTARY STRUCTURES

- Massive
- Horizontal bedding
- Cross-bedding
- Graded bedding
- Bimodal lamination
- Discontinuous bedding
- Wavy/nodular bedding
- Faint bedding (only fills part of column)
- Flaser bedding
- Herring-bone cross-bedding
- Climbing ripple lamination
- Current ripples and current rippled bedding
- Wave ripples and wave rippled bedding
- Adhesion ripples
- Sand lenses and scattered sand grains in shale
- Particle lineation
- Scour
- Convolute bedding
- Load ball
- Sand dyke
- Water escape structures (dishes and pillars)
- Mud crack
- Ruptured lamina

- Gutter cast
- Slump structure
- Flame structure
- Sedimentary fault
- Bedded clasts
- Shell/particle orientation
- Bird's eye structure
- Stromatactis
- Mottling
- Geopetal
- Algal mat/stromatolites
- Chickenwire anhydrite
- Bored surface
- Meniscus-filled burrow and *Diplocraterion* U tube
- Burrows – vertical, diagonal and horizontal
- *Teichichnus*, crustacean and amphipod-type burrows
- Bioturbation
- Collapse/solution/fault breccia
- Fracture (outside grain size column) — frac
- Joint (outside grain size column) — jt
- Slickensides (outside grain size column) — slk
- Stylolite
- Tectonic fault — F

CLASTIC PETROGRAPHY

Mineralogy

Feldspar
Glauconite
Quartz
Mica
Rock fragments A.
Rock fragments B.
Intraclasts
Heavy minerals
Ooliths
Pellets/peloids
Shell fossils
Plant fossils
Detrital clay
Lime mud
Authigenic clays.
Mineral cements.
Hydrocarbons
Visible porosity

Diagenesis

Authigenic clays:	Kaolinite
	Illite
	Chlorite
Cements:	Silica
	Feldspar
	Calcite
	Dolomite
	Siderite
	Pyrite

Diagenesis, abbreviated form

Authigenic clays:	Kaolinite	K
	Illite	I
	Chlorite	H
Cements:	Silica	Q
	Feldspar	F
	Calcite	C
	Dolomite	D
	Siderite	S
	Pyrite	P
	Poikilotopic calcite, dolomite	C–C, D–D

Principal amounts	KIH	QFCDSP
Accessory amounts	kih	qfcdsp

PALYNOFACIES

Sorting

Poor	P
Moderate	M
Good	G

Humic constituents

DOMINANT KEROGEN

Unstructured inertinite	Ui
Structured inertinite	Si
Unstructured vitrinite	Uv
Structured vitrinite	Sv
Organically degraded	
Physically degraded	

Sapropelic constituents

DOMINANT PALYNOMORPHS

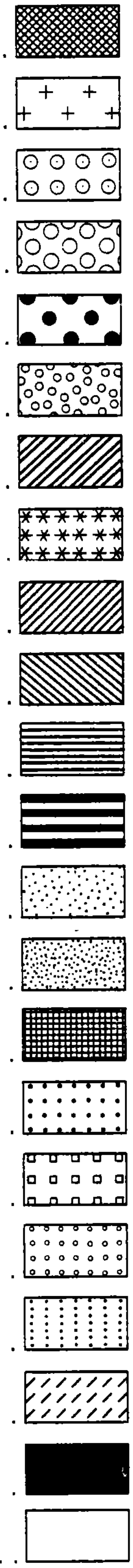
Spores		
Pollen	Gymnosperm	
	Angiosperm	
Microplankton		
Freshwater algae		F
Cuticle		C
Amorphous sapropel		S
Organically degraded		
Physically degraded		

Palynofacies

Inertinite
Vitrinite
Sapropel
Amorphous kerogen

Particle type

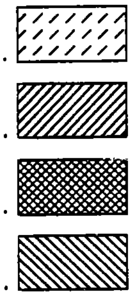
Skeletal grains
Comminuted skeletal debris
Ooliths
Coated particles
Micritic allochems
Peloids
Intraclasts/aggregate grains
Glauconite
Detrital quartz
Detrital feldspar
Detrital mica
Plant material
Lime mud
Detrital clay
Authigenic clay
Cement
Relict skeletal grains
Relict non-skeletal grains
Relict indeterminate grains
Original particle type destroyed by diagenesis
Hydrocarbons
Visible porosity



Diagenesis

Algal micritisation	M
Leaching of aragonite, calcite	Lar, Lc
Drusy calcite cement	Cdr
Blocky calcite cement	Cbl
Poikilotopic calcite	Cp
Blocky dolomite cement	Dbl
Poikilotopic dolomite cement	Dp
Neomorphic calcite (matrix)	Ncm
Neomorphic calcite (skeletal)	Ncs

Recrystallised calcite
Replacement idiotopic dolomite
Replacement hypidiotopic dolomite
Replacement xenotopic dolomite



Replacement idiotopic anhydrite	Ai
Replacement hypidiotopic anhydrite	Ah
Replacement xenotopic anhydrite	Ax
Poikilotopic anhydrite	Ap
Nodular anhydrite	An
Barytes	Ba
Celestite	Ce
Chert/chalcedony	Ch
Chlorite	Cl
Fluorite	F
Galena	Ga
Glauconite	Gl
Gypsum	Gy
Kaolinite	K
Phosphate	Ph
Pyrite	Py
Quartz	Q
Sphalerite	Sp

Porosity type

- Intergranular (including shelter)
- Intragranular
- Framework
- Vugular
- Mouldic
- Channel
- Fracture
- Intercrystalline
- Matrix

Residual hydrocarbons in pore space

- Intergranular (including shelter)
- Intragranular
- Framework
- Vugular
- Mouldic
- Channel
- Fracture
- Intercrystalline
- Matrix
- Concentrated along microstylolites

Archie classification

(a) MATRIX TYPES

Compact interlocking crystals	I
Chalky texture	II
Granular/saccharoidal	III

(b) VUG SIZES

None visible <20μm	A
20 – 125μm	B
125μm – 2mm	C
>2mm	D
Connected	c
Disconnected	d

(c) VUG PERCENTAGES

- >10%
- 5 – 10%
- <5%
- None visible
- Fracture porosity only — frac

Hydrocarbons

Hydrocarbons filling 0 – 25% of pores	◔
Hydrocarbons filling 25 – 50% of pores	◑
Hydrocarbons filling 50 – 75% of pores	◕
Hydrocarbons filling 75 – 100% of pores	●