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A PETROLOGICAL STUDY OF SEDIMENTS FROM BEACH PETROLEUM N. L. GELTWOOD BEACH WELL No. 1, OTWAY BASIN, S. AUSTRALIA

by

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SUMMARY

The Geltwood Beach No.1 Well disclosed two important characters of the stratigraphy of the Otway Basin in that area: the strong reduction of thickness of the sediments of Unit Gg (as defined for Mount Salt Well No.1, Dellenbach, 1964) and the great thickness of sediments of Lower Cretaceous age (units M and P).

The petrographic examination of the Lower Cretaceous sediments has shown a sequence of shallow water sediments in which important diagenetic changes have taken place. This sequence has been subdivided into two major units M and P which correlate with similar units intersected in the Eumeralla No.1 Well. The depositional origin of the sediments of units M and P has been considered with a view to ascertaining the source rock and reservoir capabilities; the effects of diagenesis have reduced the reservoir potential.

The stratigraphical section is as follows:

0 -	60ft	- Recent sediments	
60 -	910	- Unit Bb (Glenelg Group equivalent)	
-	960	- Unit Bc ("Nelson Formation" or Buccleuch Group).	
-	1810	- Unit Db (Dartmoor Formation)	Knight Group
-	1910	- Unit Dd (Bahgallah Formation)	Knight Group
-	2960	- Unit Gb Unnamed unit	
-	3490	- Unit Gd (Paaratte Formation)	
-	3670	- Unit Gg (Sandy equivalent of Belfast Mudstone)	
-	8955	- Unit M (Merino Group)	
-	12,300	- Unit P Unnamed unit.	

INTRODUCTION

The history of the Geltwood Beach No.1 well is well known from the reports presented at the completion of the well and at the A.P.E.A. Conference in 1964. For the sake of convenience some basic data are listed below.

BEACH PETROLEUM N.L. Geltwood Beach Well No.1

Location: Latitude 37^{o} 39' 44" S. Longitude: 140^{o} 14' 35" E.

1:250,000 Sheet : Penola J54-6-9.

Elevation : 30.03 feet K.B., 15.03 feet G.L. (above mean sea level, Port Adelaide.

Total depth : 12,300 feet (driller) below K.B. (subsidized)

Abandoned : 12th November, 1963.

The investigation of the petrology of the sediments of the Geltwood Beach No.1 well, is part of a general study of selected wells of the Otway Basin currently in review by the Bureau of Mineral Resources.

Samples of the cuttings were examined at 10 feet intervals except for the Lower Cretaceous sequence. In this monotonous sequence samples were examined and thin sections prepared at each lithological change, at each major change in electric log character and at least at 100 feet intervals. More than 170 thin-sections were prepared from cuttings and cores. A detailed petrographical analysis was made on each of these thin-sections. Heavy minerals separations were made where relevant. The results were generalized and described on the attached composite log and form the basis of this report. The thin-sections and their descriptions can be consulted at the Core and Cuttings Laboratory, Bureau of Mineral Resources, Fyshwick, A.C.T. The completion report (G.A.L., 1964) and the paper presented at the A.P.E.A. Conference (Woolley and Laws, 1964) were the basic references.

UNITS M AND P

The sediments of units M and P - equated to the "Merino Group" in the completion report (G.A.L., 1964) have been intersected in the Geltwood Beach No.1 well, from 3670 feet to the bottom of the well (12,300 feet). Thin-section analysis of the sediments has shown that marked changes have occurred by diagenesis. The degree of alteration is apparently related to the depth of burial, and the nature of the change is also dependent upon the type of strata and constituent minerals. It is important to be able to recognize the degree of diagenetic alteration of the primary minerals in order to assess the effect on reservoir characteristics and to correlate equivalent stratigraphical units from other wells.

Correlation and mapping of zones of increasing diagenesis has been described by KOSSOVSKAIA and CHOUTOV (1955) in the Upper Palaeozoic and Mesozoic terrigenous sediments of the western Verkhoianie geosyncline. Although the pile of sediments investigated by these authors is by far greater (approximately 30,000 feet) than the sequence intersected in the Geltwood Beach No.1 Well, features similar to those described in the three upper zones of the Verkhoianie geosyncline have been recognized in the Geltwood Beach sediments. The range of diagenetic alteration applies to the whole Lower Cretaceous succession of the so-called "Merino Group", but a conspicuous change in the sediments warrants a division into two units: P and M. No evidence of an unconformable relationship between units P and M could be recognized from the available material.

UNIT P

Sediments encountered from the bottom of the well at 12,300 feet to the depth of 8,955 feet have been grouped together in the Unit P on the basis of their lithological affinities and of their high content in garnets in particular. This unit may be broken down into intervals, all related to each other lithologically and showing a similar degree of diagenetic cementation.

Interval 12,300 - 11,310 feet.

The alternating tight sandstones, mudstones and shales in which the well ended at 12,300 feet recur to the depth of 11,310 feet. At 11,310 feet there is a change from low microlog resistivity to a series of high resistivity values from 11,310 to 11,270 feet. The types of rock encountered over the interval are strongly compacted chloritic mudstones and shales, and highly cemented sandstones ranging from very fine to medium grade.

Interval 11,310 to 10,080 feet.

The important increase of resistivity from 11,310 to 11,270 feet represents the choice for the lower limit of this interval. The upper limit at 10,080 feet marks a sudden upwards increase of strongly cemented sandstones. The main rock types of the interval are, as below, compact chloritic mudstones, and shales and fine to medium-grained well-cemented sandstones. The distinctive lithological characters are the lower frequency of highly cemented horizons and the abundance of lenses and stringers of coal.

Interval 10,080 - 9620 feet.

The contrasting short normal and microlog resistivity patterns, the high frequency of zeolite-cemented sandstone layers particularly from 10,080 to 10,030 feet distinguish this particular interval.

Interval 9620 - 8955 feet

The particular microlog resistivity pattern, the recurrence of strongly cemented horizons in which the drilling rate was high (generally in the range of 60 to 90 min/ft) are distinctive characters for this interval.

Generalized description of the sediments of unit P

The indurated chloritic mudstones

Dark greenish grey to brownish grey chloritic mudstones (and shales) recur throughout the unit P. Thin sections of cuttings and cores of this rock type present diverse features related to strong diagenesis. These features by themselves are not characteristic for any specific interval but the frequency of their occurrence increases with increasing diagenesis and depth. The groundmass of the sediment is mainly chloritic and clayey.

The chloritic material comprises two different types of minerals of probable different origin. Tiny (0.008 mm) tabular crystals of clear low-birefringent chlorite (prochlorite) develop in the groundmass. In many instances these crystals coalesce, forming aggregates, vermicules and films, also grading to fibrous and scaly masses which act as cement. The second type of chloritic material is in the form of flakes, clots and colloform masses of nearly amorphous brown chlorite. Transitions exist between this material and illite and biotite (chloritized biotite).

The clay minerals in the chloritic mudstones are flaky illite and a clean cryptocrystalline clay material (kaolinite group or so-called "illitized" kaolinite). Montmorillonite is present in several X-ray analyses of mudstones. This could support the hypothesis of the derivation of the montmorillonite from volcanic glass ash (Whittle in G.A.L., 1964). However, no typical shards or glass fragments have been recorded in the mudstones.

Flakes and colloform aggregates of coaly matter and finely divided pyrite are also present, together with fragments of coaly plant tissues. Cryptocrystalline (authigenic) silica and zeolite minerals have been recorded but it is difficult to assess the proportions of these minerals by means of the microscope.

The Sandstones

Sandstones with matrix

The strong influence ofdiagenetic changes masks the depositional texture of the sandstones and introduces new relationships between detrital grains and matrix. On the whole there is little variation in the proportion of the different detrital grains. Moderately to well sorted, angular, very fine to medium-grained lithic fragments (20 to 30%), feldspars (15 to 20%) and quartz (10 to 20%) make up the framework. The lithic fragments consist of aphanitic siliceous rocks of uncertain origin and aphanitic rocks of known origin: volcanic rock fragments , schists. Fragments of metaquartzite are also present. The lithic fragments are generally fresh and their detrital outlines are preserved in most cases. Many aphanitic volcanic rock fragments are brown to opaque, owing to the devitrification of the groundmass.

The feldspar is acid plagioclase, orthoclase and microcline. The quartz grains are generally very angular, and in parts of probable volcanic origin. The matrix is a compound of detritus, clay and chlorite with abundant flakes of mica and coaly pyritic matter. Since important diagenetic changes have affected the clay and chlorite minerals, and have produced new minerals, such as silica and zeolite, the term matrix must be understood as a textural concept as opposed to the cement of other sandstones in the unit P. In many instances there is a strong interaction between matrix and framework. The framework constituents are altered, corroded, in particular the feldspars are kaolinitized, zeolitized and quartz overgrowths induce a diffuse inter-penetration of matrix and framework.
Owing to the fineness of the lithic grains and the diagenetical changes, the determination of the nature of the volcanic rock fragments was difficult.
Most abundant are fragments of the groundmass of lavas with microlitic texture (andesite and trachy-andesite), with abundant silica (felsitic texture of possible dacites) and devitrified glass. Fragments of andesite, trachy-andesite and dacite were recorded. Measurement of the extinction angle of the plagioclase phenocrysts shows oligoclase and rarely andesine to be present. This is consistent with the measurements made on isolated plagioclases of the sandstone. Fragments of lavas with chlorite and quartz amygdales, lavas with chlorite, haematite and glass groundmass were also recorded.

There was no definite evidence for fragments of tuffs (vitric or lithic), but the freshness of parts of the volcanic material could support the view that volcanic activity (flows) was penecontemporaneous of the sedimentation.

It is possible, considering the content of volcanic rock-fragments in unit P in other wells, that the volcanic suite in the reworked constituents described, appears more acidic than it was initially owing to maturation processes during deposition. Conversely isolated mafic minerals are rare among the constituents of the sandstones.

Crystalline zeolite may develop and "digest" part of the matrix, particularly in the interval 10,080 to 9620 feet. Patches of recrystallized calcite are corroding and replacing parts of the matrix and the framework. Little porosity and no permeability are to be expected from these sandstones.

Sandstones with cement

The sandstones with cement show a similar framework to that of the sandstones with matrix. Similarly the sorting is medium to good and the grain size very fine to medium. At some horizons the quartz and feldspar grains have detrital outlines and the lithic fragments have simple straight or subrounded boundaries. These sandstones are calcite-cemented subgreywackes (Pettijohn, 1957). In other calcite-cemented sandstones of the unit P the calcite clearly replaces a clayey chloritic matrix and parts of the framework. Relicts of the matrix and of chloritic coatings, also of detrital feldspars and quartz grains, occur in a strongly recrystallized, partly megacrystalline pure calcite "cement". These sandstones with "replacement cement" belong to a greywacke and subgreywacke suite. At several depths these sandstones merit the name "volcanic sandstones" in the sense that most framework constituents are of volcanic origin.

A particular type of cement occur in the form of clear poikilitic zeolite (low axial angle positive and negative minerals). This replacement cement is particularly abundant in nearly half of the thin-sectioned cemented sandstones from cores and cuttings between 11,310 and 8955 feet.

The zeolite cement replaces parts of the matrix and the feldspar grains, and contains relicts of feldspar grains, of chlorite coatings and of detritus. The zeolite cement is a late diagenetic product but may itself be replaced by calcite (e.g. 11,230 feet). Authigenic heulandite was first recorded in sediments of the "Otway Group " in the Flaxman's No.1 well in Western Victoria (Baker and McAndrew, 1961).

A zonation of different types of zeolite minerals was not apparent in the zeolite sandstones of unit P (Coombs, 1954) of the Geltwood Beach No.1 well. At 11,800 feet and more generally between 10,800 and 11,600 feet a strongly developed quartz cement has been observed in the thin-sections. Interpenetration, pressure - solution, growth and development of a mosaic texture affect the quartz, quartzite and feldspar grains. The silicification is responsible for the partial digestion of the matrix and the obliteration of any possible porosity. The welding and interlocking of the detrital grains due to silicification is responsible for the velocity of approx. 15,000 f.p.s. recorded between 10,800 and 11,600 feet (Appendix 6 in G.A.L., 1964).

It is evident from the examination of the cores and cuttings of the sandstones with cement that minor porosity may occur where the diagenetic changes have been incomplete, but erratic distribution and lack of continuity of this porous space will not allow for any permeability.

Heavy Minerals

One of the most distinctive characters of the sandstones of Unit P is the high content of heavy minerals. Although similar assemblages of heavy minerals occur in the different types of sandstones, the presence of abundant heavy minerals is generally related to the sandstones with calcite or zeolite cement. The relation with medium to coarse-grained quartz and metamorphic rock fragments is also obvious. Apatite, chloritoid, epidote, garnet, leucoxene, monazite, tourmaline, sphene, zircon and opaque minerals have been recorded in all thin-sections of cores and cuttings of the unit P.

Particularly striking was the observation at recurrent intervals below 9050 feet where it was first detected, of sandstone chips with abundant pink garnet (almandin) together with the other mentioned minerals. The amount of garnet grains can be as much as 10% of the total detrital grains of a single cutting fragment. These recurrent cuttings are parts of heavy minerals rich sandstone laminae which indicate a concentration due to turbulent conditions of deposition. It should be pointed out that thin sections taken from the cores of unit P did not emphasize the presence of these heavy mineral rich sandstone laminae except at 11,234 feet (core 27). The nature of the heavy minerals, together with other characters of the sandstones, such as sorting, grain-size, absence of matrix, abundance of metamorphic rock fragments (some with minerals), indicate some variation in the provenance of the constituents in various horizons within unit P. The source of the constituents of metamorphic affinities is reminiscent of the source of the sediments of unit R in the Pretty Hill No.1 well.

Minerals with authigenic habitus such as the titanium bearing minerals: leucoxene, sphene, and rutile, and also epidote-group minerals (clinozoisite?) have been recorded. Most thin-sections made from the unit P show that euhedra of sphene coated with cryptocrystalline leucoxene have developed in the intergranular space. However, it should be stressed that the minerals mentioned above together with apatite and garnet occur as inclusions in metamorphic rock fragments. The removal of these minerals from the host-rock during sedimentation and by diagenetic processes, and the adjustment of some of them to the intergranular space could account for their authigenic appearance.

Lithology and electric log characteristics

Interval 12,300 - 11,310 feet :

Core 29 and 28 show thin laminations (0.2mm thick), low-angle planar or slightly curved (trough) cross-beddings, scour-and-fill and load structures. The alternation of indurated mudstones, shales, and sandstones in thin laminations, the presence of minor coaly horizons, the differentiation of layers of subgreywacke composition, the response of these diverse rock - types to strong diagenetic processes, all these characters account for the great and numerous variations of resistivity over the interval.

Interval 11,310 - 10,080 feet :

Similarly to the previous interval thin laminations, undulate laminations, low-angle cross-bedding, small scale load structures and slumpings are common in the cores of the interval. The cross-bedding in cores 25 and 27 is slightly curved (trough) with sets of laminae dipping at less than 20° in probable foresets. The overall sequence of sediments is flat-lying. Although cuttings observation tends to indicate fairly homogeneous lithology over the interval, some changes can be detected. One is the presence of coal at several horizons especially between 11,230 and 11,200 feet. The microlog shows that the number of porous horizons decreases below 10,800 feet. The bottom forty feet of the interval shows strong resistivity on the microlog and corresponds to strongly cemented sandstones.
(The presence of small grains of glauconite, mentioned from core No. 27 - 11,231 - 11,232 feet and 11,232 - 11,243 feet - (Whittle, in G.A.L., 1964) could not be substantiated.)

Interval 10,080 - 9620 feet :

The choice of this interval is based on a distinctive pattern of resistivity, the higher frequency of volcanic sandstone layers and the occurrence at the base of the interval of 50 feet of medium to coarse-grained subgreywacke with "unit R affinities". The core 24 at 9857 to 9867 feet is representative of the diagenised mudstone. It is a tight, hard, medium grey, strongly silicified (chalcedony) chloritic mudstone with discrete zeolite. Some erratically distributed medium-grained quartz grains are present. Core 24 did not show any sandstone. Thin-sections of sandstone cuttings of the interval show well-developed poikilitic zeolite and replacement calcite cement.

Although the core 24 was not representative for the different rock types of this interval, the characters of the cuttings and the electric log pattern suggest alternations of thinly laminated sandstones and shales, with a greater frequency of zeolite and calcite-cemented subgreywacke at base.

Interval 9620 - 8955 feet :

Core 23 (9360-9370 feet) is a good example of a very fine-grained sandstone with replacement calcite cement. The process of cementation has rendered the rock very massive and tight . It is apparent that the sandstone was finely laminated before diagenesis. The usual dark coaly and pyritic laminations emphasize the undulations, ripple-marks and low-angle cross-bedding. The grey mudstone which is represented in the samples of core from 9369, 9367 and 9363 feet is also very tight, micaceous and finely carbonaceous. These cemented sandstones and indurated mudstones alternate regularly (possible cycles) over the interval, as shown by the electric log. The upper limit of the interval has singular stratigraphic significance for it marks the topmost occurrence of an assemblage of abundant heavy minerals equivalent to that of unit P in the Eumeralla No.1 well.

Environment criteria for the unit P

The thin laminations, low-angle cross-bedding, small-scale scouring, undulate laminations, together with the presence of coal, indicate shallow water conditions. The presence of subgreywackes, the variations in grain-size, sorting, the origin of the detrital grains, the concentrations of heavy minerals and the occurrence of structures such as ripples and fore-set cross-bedding indicate recurrent high-energy conditions. The occurrence of coaly plant fragments and coal lenses contrasts with the presence of subgreywacke containing depositional calcite cement and indicates a transitional environment with changing non-marine and marine influences.

Note. Occasional fractures have been reported in the completion report (G.A.L. 1964) in core 23 and in various other cores (cores 26 and 27) within Unit P. However, these fractures or fissures could not be substantiated in the samples of cores available. At 10,600, 9400, 9030 feet in cuttings thin-sections and at 9857 feet (core 24) fissures infilled with calcite, zeolite and chlorite were recorded.

Unit M

The Unit M extends in the Geltwood Beach No.1 well from 8955 to 3670 feet and is unconformably overlain by unit Gg. The lower limit is well marked at 8955 feet by the increase in resistivity from 8955 to 8900 feet and the change in the nature of the sandstones. There is no evidence for an unconformable relationship between units M and P. The change from unit M to unit P at 8955 feet is also suggested by the 18,000 f.p.s. refractor at 9,000 feet mentioned by Woolley and Laws (1964).

The unit M has been divided into 6 intervals on the basis of the lithological character of the sediments and changes on the electric logs.

Interval 8955-8100 feet :

The upper limit of this interval is taken at 8100 feet. Chloritic mudstones and strongly cemented very fine grained sandstones (greywacke and subgreywacke) are recurrent over this interval. The caliper-log and the drilling rate also indicate a high degree of cementation.

Interval 8100 - 7000 feet :

Although there is little change in the rock type of this unit as compared with the previous one, the degree of cementation is less and the frequency of clay rich horizons is greater. Low resistivity peaks on the micronormal curve become very frequent from 8100 to 7000 feet. The upper limit at 7000 feet is marked by a sudden increase of the resistivity from 7000 to 6900 feet.

Interval 7000 to 6070 feet.

The sediments intersected in this interval are similar to those of the interval below. The major difference lies in the lesser amount of poikilitic zeolite cement and the greater frequency of clay matrix in the sandstones.

The reason for the choice of the upper limit of this interval at 6070 feet is based on the change in the microlog from a succession of high and low resistivity peaks below 6070 feet to an overall high resistivty zone from 6070 to 5820 feet.

Interval 6070 - 5250 feet :

Particular to this interval is the gradual decrease from bottom to top of the calcite-cemented sandstone layers marked by high resistivity peaks.

Interval 5250 - 3990 feet :

The sediments of this interval are alternating chloritic mudstones with coal fragments, shales and sandstones of greywacke nature with frequent replacement calcite cement. The sequence is fairly homogeneous with minor horizons showing increased porosity at 4770 and 4120 feet which correspond to sandstones with abundant volcanic constituents, and a partial development of non-poikilitic zeolite (analcime-group) and chlorite cement. These characters are reminiscent of the zeolite-bearing horizons at the top of unit M (7700-7800 feet) in the Flaxman's No.1 well (Baker and McAndrew, 1961). Current petrographic investigations will ascertain the validity of this correlation.

Interval 3990 - 3670 feet :

This interval of 320 feet thickness is characterized by the variations in the resistivity and S.P. patterns, and the presence of a siderite cement. Similar characters, indicating possible more marine influences have been noted in other wells in the western subbasin.

The important change of lithology and regional considerations suggest that an unconformity marks the top of the unit M at 3670 feet.

Generalized description of the sediments of the unit M

The chloritic mudstones and shales

The microscopic examination of samples of the greenish grey to brownish chloritic mudstone and shales, shows the groundmass of the rock to be composed of:

- a cryptocrystalline clay material (kaolinite group*) passing to scaly illitic clay aggregates. The frequency of the occurrence of this clay mineral increases noticeably below 7000 feet downwards.
- concentrations of greenish brown chloritic material and chloritized biotite.
- non-opaque detritus ranging in size from 1/100 mm to very fine grade. The siltsize particles are mostly acicular quartz and feldspar fragments and shreds. The very fine-grained detritus is quartz and feldspar and does not differ in nature and proportions from the framework of the sandstones with matrix.
- opaque detritus among which pyrite and coaly matter are predominant.
- variable but minor amounts of coarse to medium-grained angular quartz grains, erratically distributed in the mudstones. Rounded intraformational mudstones fragments are associated with the sandy horizons.

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* An X-ray analysis carried out on the clay fraction of a sandstone at 5336 feet (core 14) shows the presence of approximately 20% kaolinitic clay in the detrital matrix.

The sandstones with matrix

Good sorting, very fine grade and marked angularity are characters common to the sandstones of unit M. The content of lithic fragments varies between 25 and 40%. Most of the lithic fragments are aphanitic siliceous rocks. Some of these display an obvious volcanic origin, and some belong to a low-grade metamorphic suite. Numerous fragments are strongly chloritic. Feldspar (15 to 20%) is acid plagioclase, orthoclase (some zoned), and minor anorthoclase. Quartz is subordinate (5 - 15%). Quartz grains are either clear and very angular (volcanic quartz in parts) or with inclusions and also composite. Quartz grains are in many instances packed together and welded.

Except for the important development of zeolitic cementing media, the matrix can essentially be termed as clayey and chloritic. Several types of clayey chloritic matrices have been observed:-

- a nearly opaque microscopically ill-defined compound of chlorite, brown-coloured in some parts, and unidentifiable clay and silica with varying amounts of detritus ; this is the case in core 16 (6088 feet) for instance where "pockets" of clean, well-crystallized clay material of diagenetic, origin, are also present;

- a pure, well-crystallized clay material (kaolinite group?) with minor amounts of detritus and pyrite;

- a pure greenish to yellowish brown chlorite group material either filling in pores or occuring as scaly masses or as coatings grading to illitic material. All transitions exist between chloritic material and illite and in many places (e.g.8900 feet), detrital micaceous material has been altered to chlorite and illite and incorporated in the matrix.

In more than half of the thin-sections prepared from sandstone fragments of the unit M, the matrix is replaced by poikilitic zeolite. The "arkosic sandstones" recorded between 8900 to 8430 feet in the completion report (G.A.L., 1964) do not correspond to any appreciable change in the nature of the framework but represent zeolite-replaced matrices. The possibility of cryptocrystalline zeolite occuring with cryptocrystalline silica in the clayey chloritic matrix could not be verified in thin-section.

Sandstones with calcite cement

The framework of these sandstones does not differ from that of sandstones with matrix. The reason for the distinction of the sandstone with calcite cement as a category lies in the fact that they could represent "subgreywacke" (Pettijohn, 1957). However subgreywackes are rare in unit M. At 5850 feet the detrital grains are coated with chlorite and embedded in a pure calcite cement which could be of primary depositional origin. In all other cases, corrosion features, ghosts of detrital grains, patches of non-calcitic matrix, poikilitic development of the calcite, indicate a replacement of the matrix and parts of the framework of greywackes by calcite. It is not possible to draw any inference about the reasons for the replacement nor about the origin of the calcite. At 7700, 7760 feet good examples of sandstones rich in volcanic rock fragments were recorded, and these warrant the name of calcite-cemented volcanic sandstones.

Although the porosities recorded in the sandstones of unit M are markedly higher than in unit P, the permeability is variable and low below 5338 feet (core 14).

The possibility that fracture porosity may occur in sediments of unit M could not be substantiated.

Heavy Minerals

In nearly all thin-sections apatite, epidote, garnet and sphene are represented in minor amounts; tourmaline and chloritoid are rare. The heavy minerals content of the sediments of unit M is much lower than in unit P and the distribution is more uniform. However, in some instances (7480, 7300 feet) the heavy minerals are concentrated in particular laminations. Epidote and sphene-bearing rock fragments have been recorded. These indicate reworked metamorphic rocks of similar origin to those observed in unit P. No authigenic minerals such as sphene and leucoxene have been definitely recorded in the unit M.

Lithology and electric log characters

Evidence from the observation of the cores and the electric log patterns suggest that except for the presence of some rather massive mudstone layers, thin laminations of shales alternate with the very fine-grained sandstones. All cores present examples of thin (1/10 mm) laminations, undulations, low-angle planar or slightly curved cross-bedding, small scale scouring and slumping. A feature specific to unit M and mentioned in the completion report is the presence in several cores of plant roots in growth position. These subvertical roots are characterized by a coaly peripheral layer and a "core" of a brownish clayey soapy material. At 8051 feet (cores 20) barite crystals develop in the centre of the roots. Similar developments of calcite in the centre of the roots are recorded in the completion report. Rootlets, parallel to the bedding, are also present (e.g 6522 feet).

Although variations in the distribution of the different rock types and the resistivity pattern suggest some sort of broad repetitive deposition; the evidence is considered to be insufficient to ascertain the cyclic nature of the sediments of unit M.

A special mention must be made of the occurrence of minor amounts of siderite in the interval 3990 - 3670 feet. The siderite is either dispersed as small rhombs in the cementing agents of the sandstones or is in the form of spherulitic aggregates in the mudstone. These features are reminiscent of the facies of sediments of the unit M in other wells (Casterton area). They could indicate a possibly stronger marine influence at the top of the unit M.

Unit Gg

This unit was first described in Mount Salt Well No.1 and represents a sandy facies of the "Belfast Mudstone". The lower limit of this unit has been chosen at 3670 feet - thus very similar to the depth of 3680 feet mentioned in the completion report (G.A.L.,1964). An unconformity is postulated at 3670 feet on the basis of the change in lithology, and this is also supported from a regional point of view.

The upper limit of this unit (3490 feet) is difficult to ascertain due to the fact that there is a transition to the lithology of the next unit Gd, and that the soft rocks of the top of unit Gg are readily destroyed by the drilling action and the quality of the cuttings is poor. The best indication is a change in the sand grain-size between 3500 and 3460 feet, from a low and variable to a high and constant percentage of very coarse sand grains and granules.

The characteristic rock type over the interval is the dark sandy mudstone. The groundmass is an amorphous or cryptocrystalline clay material with finely divided chlorite. Very typical is the occurrence of well dispersed brown to reddish microcrysts of siderite. Siderite occurs also as cryptocrystalline aggregates (0.10 to 0.20 mm). Finely divided pyrite and organic matter is present throughout. Brown to black coaly plant fragments are common. , Reddish brown spores are present in thin-sections of core 7 (3632 feet). The silt-size detritus is very angular and consists of corroded quartz and subordinate feldspar. The sandy parts contain angular to sub-rounded, medium to very coarse-grained quartz, metaquartzite, chalcedony, minor feldspar (orthoclase). These constituents are either scattered in the mudstone or concentrated in lenses. Some of these lenses with very coarse-grains display a cryptocrystalline sideritic cement or also pyrite cement. No volcanic rock fragment have been recorded in thin-section, in great contrast with the unit M below. Another feature of these mudstones is the abundance of flaky material: muscovite, biotite, chlorite, organic matter and discontinuous laminae of pyritic material. The presence of the laminae and flaky materials produce a shaly character.

The core 7 displays grey laminated mudstone with lenticular sandy layers with siderite cement or clay matrix. The siderite cement is recrystallized in some places in booklet-like structures (length 1mm, width 0.4mm). The occurrence of alleged glauconite mentioned in the completion report could not be substantiated by the observation of the small fragments of the available cutting. Quartz grains with green (chloritic) inclusions have been recorded at 3590, 3550, 3520, 3500 feet, and chloritic rock fragments are frequent in the thin-sections.

The facies described in unit Gg, although consisting of similar mudstones as in the Mount Salt No.1 well, is generally more sandy and contains gravels. This change is probably related to the overall reduced thickness, favouring the hypothesis of a deposition on a structual high. Core 7 at 3632-3647 feet consists of sandstone and laminated sandy mudstone with abundant carbonaceous flakes. Although the characters of the sediments still indicate a deltaic environment, the granularity and the abundance of siderite together with the markedly different source of the terrigenous content, differentiate strongly this unit from unit M.

Unit Gd

The unit Gd (equivalent to the Paaratte Formation) is present in the Geltwood Beach No.1 well from 3490 to 2960 feet.

Lower Limit

The lower limit of the unit Gd has been taken as previously mentioned, at the depth of 3490 feet, based on a change in the sand grain-size. It is felt however that although the mudstone interbeds which are dominant in unit Gg, occur at the bottom of unit Gd, their frequency gradually decreases.

Upper Limit

The upper limit at 2960 feet is well marked by a change from coarse to very coarse-grained sands and abundant pebbles, together with the introduction of coaly lenses in the unit Gb above.

The main difficulty in the petrological study of the material of the interval was to assess to abundance and the nature of the cavings.

It is evident that cavings recur throughout the interval. Chert fragments from the nearby limestone interval of unit Bb, fragments of glauconite rock (from the top of unit Bc) were obvious cavings. he more difficult problem with possible caved lithologies was the occurrence of iron oxide and siderite rich fragments which would possibly have been caved from the unit Dd or above. Obvious cavings from the unit Dd occur in the form of sideritic-chamositic-quartzose sandstone containing oxidized chamosite ooliths. Nevertheless the thin-sections of cuttings show reddish siderite to be present as part of the cementing media of the unit Gd sandstones.

The sandstone typical for the unit Gd is a clean angular to subrounded, fine to coarse-grained quartz sandstone. The sorting is good in most instances, but some samples show scattered very coarse quartz and quartzite grains. The lithic elements are metaquartzite, minor chalcedonic rock fragments, and rounded chloritic rock fragments which in some instances make up as much as 10% of the rock. Minor orthoclase and microcline grains (few percent) are present. Tourmaline and zircon have been observed. Another typical feature of the sandstone of unit Gd is the relationship of grains and cement. The rather loose packing of the detrital grains with little or no contact, the even distribution of the cement, are very characteristic features.

The cementing medium is carbonate and is thought to be of depositional origin. Generally the carbonate is in the form of tiny euhedral crystals of siderite. Siderite spherules as big as 0.25mm in diameter develop at 3000 feet, in the interstices of a sandstone. This spherulitic siderite owes its origin to recrystallization during diagenesis. The nuclei of these spherules is in some instance of a chamositic nature. Chamosite, clay, pyrite and detritus are among the cementing media, but siderite, calcite and dolomite are preponderant. The carbonate cement has a corrosive effect on the quartz and feldspar grains which either show embayments or possibly also a restored euhedral aspect due to selective solution. Pockets of well-crystallized kaolinite are present though rare. Limonite and hematite are common and finely divided. Recurrent instances of pure siderite rock fragments account for the probable presence of thin layers or lenses of siderite rock. This type of rock is typified by its finely dispersed haematitic material , giving a strong red coloration to some cuttings fragments. Also typical is the presence of minute carbonaceous flakes or fragments of plant tissue. Some spores have been noted. Minute crystals of pyrite and marcasite are common. Although the samples of cuttings selected for thin-sectioning are necessarily well cemented, the porosity of the unit as a whole is considered as fair. The interval 3400 - 3100 feet is more cemented as indicated by the resistivity on the electric log. The only portion of core available over this interval is a sandstone with mudstone laminations. It is not representative of the main lithology as deducted from the observation of the cuttings. The sandy laminations show rather poor sorting and contain abundant opaque and chloritic material and muscovite. The observation of the cuttings and the electric log suggest that sandstones with varying amounts of possibly patchily developed cement alternate with layers of mudstone over the interval.

The environmental conditions inferred for the deposition of the sediments of the unit Gd are similar to those inferred for the same unit in different wells (Port Campbell No.1, Mount Salt No.1). These conditions suggest deposition in an outer deltaic zone where marine influence was dominant.

Unit Gb

Unit Gb has been intersected in the Geltwood Beach No.1 Well between 2960 and 1910 feet.

Lower Limit

The lower limit at 2960 feet is marked by a conspicuous change in the grain-size with an increase in content of coarse-grained sands and gravels. Also the passage from a moderately cemented sandstone in the unit Gd to sandstones with varying but low degree of cementation, is very noticeable. Finally, the influx of coal fragments, among the cuttings above 2960 feet is good evidence for the chosen limit.

Upper Limit

The upper limit of this unit is well marked by a change to the lithology of unit Dd. This change strongly supports the hypothesis of an unconformity at 1910 feet.

The main rock types recurring over the interval are argillaceous sandstones, mudstones and coal lenses.

The argillaceous sandstones

The cuttings samples display loose quartz grains (pink, milky or with dark inclusions) minor feldspar grains, and some dark grey rounded siliceous rock fragments. Fragments of red sandy siderite are also recurrent. Owing to the presence of obvious cavings (chert of unit Bb, glauconite-rock fragments, oxidized chamosite ooliths from unit Dd), it is difficult to assess the position of the siderite lenses within the alternating mudstones and argillaceous sands. The sandstones or the poorly consolidated sands are composed of subangular to subrounded, medium to coarse grains of quartz (also pink quartz), metaquartzite, siliceous rock fragments (chalcedony), minor feldspar and chloritic rock fragments. Granules of quartz, metaquartzite and rock fragments are frequent throughout the interval, though apparently erratically distributed. Mica flakes are present. The soft bonding media are clay and silt, with abundant flaky material: mica and carbonaceous matter, and abundant pyrite and marcasite. Siderite is finely dispersed in the matrix of some samples. As previously explained, the cuttings of sideritic silty lenses are difficult to allocate to specific horizons in view of the possibility of caving, but some, undoubtedly belong to the lithology as shown by core No.4. The presence of carbonate rich lenses indicates a slightly stronger marine influence in this regressive facies, compared with the Mount Salt No.1 well.

The Mudstones

Dark pyritic silty mudstones have been intersected in the cores 4, 3 and 1. They display a brown to grey brown subopaque clayey groundmass with abundant pyritic and coaly matter. Silt and sand-size detritus is moderately abundant and in some instances reaches 30 to 40%. It is made of angular silt-size to very coarse-grained quartz, metaquartzite and minor chalcedony and feldspar (orthoclase and rare acid plagioclase). Rounded tourmaline grains are present. Mica (mainly muscovite) occurs throughout.

Lithology and electric log characteristics

Available samples of cores 4, 3 and 1 show rather massive mudstone, plastic when wet or with conchoidal fracturing. Very thin (fraction of a mm) light grey clayey, silty to sandy laminations are flat-lying and pass laterally within the core to lenses varying in size from one cm in diameter up to several inches.

Some of these lenses are elongate and have an asymmetric section. The most curved part is at the bottom, These features represent infilled furrows made of very fine-grained clear sands grading into silt and clay at the top. In the bedding plane of the sandy laminations medium to very coarse quartz and quartzite grains occur irregularly. The cementing media of these laminations are either clay or yellowish to buff siderite. Pyrite and iron sulphate are present. Thin coaly horizons or lenses recur.

Although affected by the phenomenon of vertical invasion, by ground water, the electric logs, especially the short normal log, particularly between 2960 and 2200 feet, depicts what can be related to a cyclic sedimentation of mudstone and sandstone.

Environment criteria

The same regressive environment applies to the deposition of the sediments of unit Gb in the Geltwood Beach No.1 well as in all currently studied wells of the Otway Basin.

Unit Dd

The unit Dd is present in the Geltwood Beach No.1 well from 1910 feet to 1810 feet.

Lower Limit

The lower limit at 1810 feet is marked by a change in lithology which is well substantiated by the electric logs.

Upper Limit

There is an important decrease of resistivity above 1810 feet and a change in the lithology. The characteristic rock type of the unit Dd is a sandy chamositic oolite. The medium size brownish red oxidized chamosite ooliths are set in a groundmass of silty siderite, chamosite and limonite with abundant microcrysts of pyrite and marcasite. The matrix present in some fragments is composed of angular to subrounded quartz and metaquartzite grains, and minor chalcedony grains, varying in grain-size from silt to very coarse grade. Some reworked shell and echinoderm fragments are present. Although no core intersected this horizon, it is thought from the cuttings observation that several oolite beds occur in this argillaceous sandy siltstone interval.

Environment criteria

Similar to other occurrences of chamositic oolite found in currently studied wells of the Otway Basin, the sediments of the Unit Dd represent a transgressive facies.

The basic characteristics for this unit are high energy conditions and availability of iron evolving from erosional and climatic processes on a nearby landmass.

Unit Db

The lowerlimit of this unit is well marked on the electric logs by the decrease of the resistivity and the negative (in relation to shale base-line) S.P. peak at 1810 feet. Also the grain-size and the nature of the sediments changes at this depth.

The upper limit of the unit is taken at 960 feet where a well marked change occurs in the lithology and the electric log.

The unit Db has been subdivided from a petrological point of view into two sub-units on the basis of the grain-size.

Sub-unitDb$_2$ (1810 - 1480 feet)

The sub-unit Db$_2$ is composed of argillaceous silts and sands or poorly consolidated sandstones. The lower part of sub-unit Db$_2$ is rich in red silty siderite.

The sub-unit Db$_2$ is richer in clay than the sub-unit Db$_1$ as in the Nelson Bore and the Mount Salt No.1 well. The argillaceous silts are dark and pyritic and contain abundant microcrysts of opaque minerals and flaky material; muscovite, and transparent plant material (? cuticule fragments). The recovered loose sands and silts are composed of silt-size to very coarse-grained subangular to subrounded clear or milky quartz grains, some of which have white (?kaolinite) inclusions. Minor metaquartzite, feldspar (microcline, acid plagioclase) and chalcedony grains are present.

The high clay content (up to 40%) of the cuttings of sediments from the sub-unit Db$_2$ did not permit the use of the usual sieving operation, carried out on "loose sands" for the grain-size analysis.

Sub-unit Db$_1$ (1480-960 feet)

The sub-unit Db$_1$ consists of loose sands and clayey silts. The grains are angular to subrounded coarse to very coarse quartz grains and minor metaquartzite, chalcedony, and minor rock fragments. Minor lenses or patches with siderite cement are present. Coal fragments indicate that minor thin layers of coal or lenses of reworked coaly material occur between 1400 and 1300 feet. From 1170 to 960 feet, the silt and clay content is high. Cavings are abundant from 1240 to 1050 feet.

Lithology and log characteristics of unit Db

No core has been taken from unit Db. It is felt that the lithology consists of thinly bedded alternating clayey sands or poorly consolidated porous sandstones and clayey siltstones. From the cuttings observations it is not possible to ascertain the presence of burrows and sedimentary structures as encountered in the unit Db of the Mount Salt No.1 well.

The electric logs are strongly affected by the vertical invasion phenomenon. The caliper log indicates that sediments of unit Db$_1$, are affected by caving and are less cemented by clay than the sediments of unit Db$_2$.

Environment criteria

A paralic environment is inferred for the deposition of the sediments of unit Db. Similar to the unit Db in the Mount Salt No.1 well, the lower part of the unit is more marine and contains more clay than the upper part. Unfortunately due to the absence of cores, closer comparison of the sediments of unit Db in the two wells, was not possible.

Unit Bc

Unit Bc is represented in the Geltwood Beach Well No.1 by 70 feet of sediments, from 960 to 890 feet. The lower limit of unit Bc is well established both on the electric log and by the change in lithology suggesting an unconformity.

At 20 foot glauconite horizon marks the top of unit Bc (from 910 to 890 feet). At 910 feet there is a decrease in resistivity and an influx among the cuttings of very coarse-grained sandstone with subrounded grains and granules. Limonite pellets are abundant. Minor intercalations of siltstones, rich in iron oxide are inferred from 960 to 910 feet. Fish teeth are common. Thus the sediments of unit Bc are very similar to those of the unit Bc in the Mount Salt No.1 well and the Mount Salt Structure holes 3, 4 and 5. The inferred environmental conditions are those of highly agitated, oxidizing waters with little influx of terrigenous material.

Fragments of glauconite rock from the glauconitic horizon (910 to 890 feet) first appear in washed cuttings from the sample taken at 890-900 feet. Thin-sections of cuttings show that the compact bright green rock consists of glauconite, or clayey and slightly calcareous glauconite with abundant foraminifera (i.e. globigerinids) with shell and echinoderm fragments. Oxidized glauconite, limonite pellets, ooliths and reworked limonitic rock fragments are frequent within the rock. Minor amounts of fine-grained quartz are present, some of which form the nuclei to ooliths. The discrepancy in depth of this interval as compared with the completion report is due to the fact that the first record of the glauconite rock is at 890-900 feet* to which depth corresponds a change on the electric log. Conversely at 910 feet (sample 910 - 920 feet) is the first occurrence of iron stained coarse quartz grains which are typical for the interval 960-910 feet. The decrease in resistivity strongly supports the limit at 910 feet. The attribution of this glauconite horizon to the Upper Eocene Buccleuch Group is supported by weak microfaunal evidence (G.A.L., 1964). Lithologically, this horizon marks the onset of the transgression continuing during Oligocene time, and is distinct from the limonitic sandstones (960-910') which emphasize the unconformity between unit Bc and Db.

*(It should be pointed out that cavings of the glauconite rock occur as low as 3230 feet).

Unit Bb

From a purely lithological point of view two intervals have been traced within the unit Bb (or Cambier Limestone).

Spicular limestone interval (890 - 710 feet)

Grey slightly glauconitic marly limestone with abundant fossil fragments (polyzoa, foraminifera, shell fragments) and very abundant sponge spicules forms a distinctive lithology over the interval. Medium to dark grey chert nodules and silicified limestone lenses are present (cavings of these chert nodules are to be found in the cuttings samples of units Gd and M).

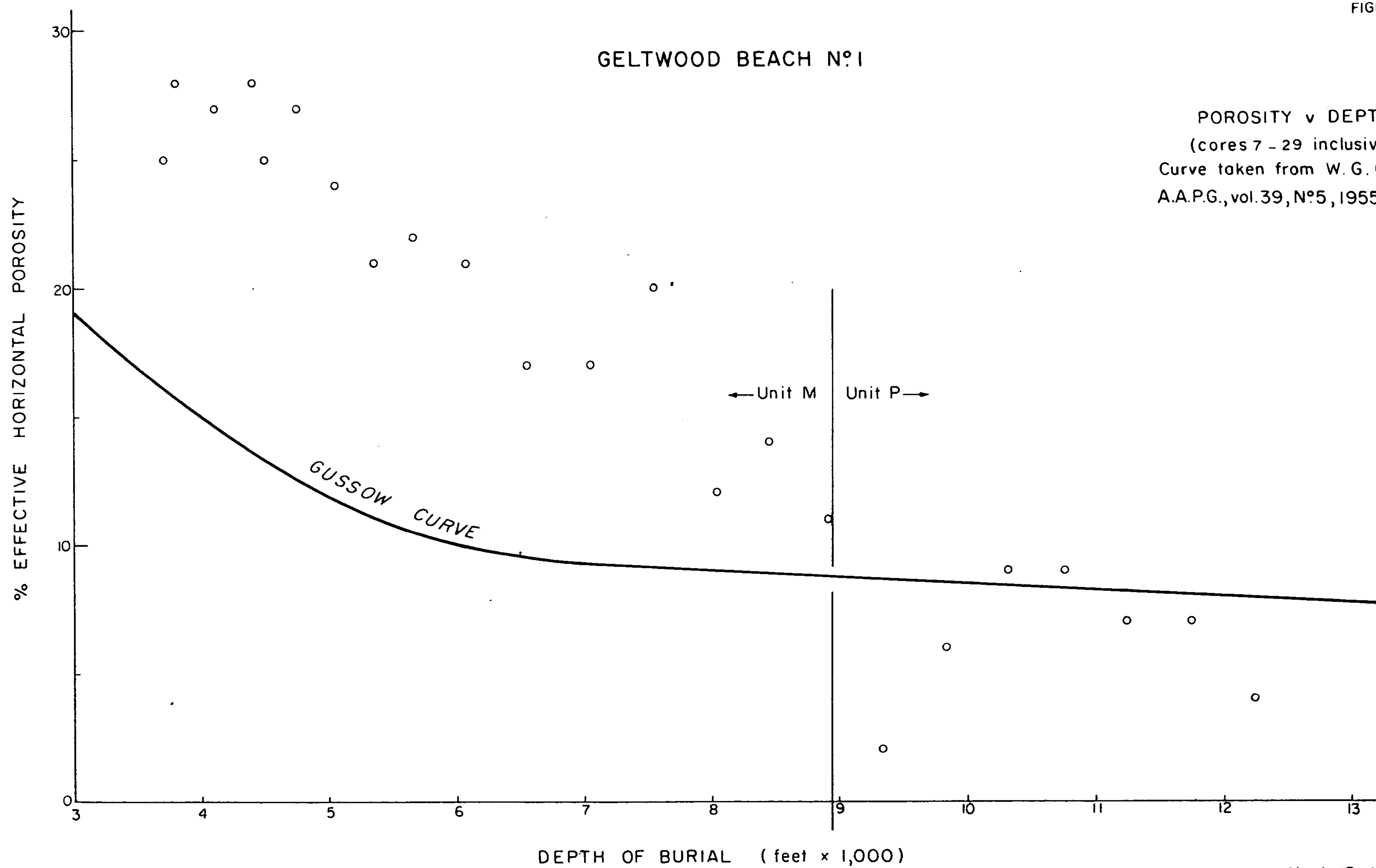
As mentioned by Ludbrook (1962) the spicular limestones are similar in nature, thickness and age to those found in the Mount Salt Structure Holes No. 3, 4 and 5.

Polyzoan limestone interval (710 - 60 feet)

The soft yellowish grey chalky calcarenite and marls contain abundant fossil debris (polyzoa, foraminifera, shell fragments). Dark grey chert nodules and lenses of cherty limestone are present throughout the interval but are especially abundant at 320 and 180 feet. No great variations in the dolomite content could be recorded. Glauconite is present. Phosphate grains or phosphatic infillings of fossils are present but rare.

The sediments of unit Bb suggest shelf environment.

FIGURE I



X AUS-2-50

Bureau of Mineral Resources, Geology and Geophysics. May 1965. To accompany record Nº 1965/41.

F.E.

Recent Sands

Loose yellowish to creamy rounded fossil debris forming a calcareous sand with minor rounded quartz grains, occur from 60 feet to surface.

Conclusions

The Geltwood Beach No.1 Well bottomed at 12,300 feet in a sequence of terrigenous sediments highly altered by diagenesis. There is no evidence for an unconformity within this sequence, but difference in texture and nature of the sandstones permits the division of this sequence into unit M (3670-8955 feet) and unit P (8955 - 12,300 feet). Unit P has clear affinities with unit R ("basal sandstone" unit) encountered in the Pretty Hill No.1 well. Unit P can be considered as a basinwards lithofacies equivalent of unit R. However, further studies of wells closer to the Pretty Hill area and intersecting the full sequence would be necessary to ascertain the probable relationship between units P and R. The sediments of unit M are similar to those of the same unit in different wells of the Otway Basin. They constitute a thick subsiding sequence of paralic sediments of greywacke affinities, thought to have been deposited for the most part in a swampy lagoonal environment.

Coal layers and disseminated coaly plant fragments are abundant throughout unit P. The presence of coals and the inferred environment suggest that the evolution of the organic matter was directed in the depositional phase towards the formation of coal. A survey of the fixed carbon in the coaly material is proposed as a means to test whether, as suggested by the petrological study, the coals contain more than 70% fixed carbon. In this case no liquid hydrocarbon would have formed. The possibility that quantities of dry gas have formed exists and is supported by results of drill-stem test No.3.

The possible existence of suitable reservoirs in units M and P is however, in question. The strong diagenesis and cementation by authigenic or recrystallized minerals points to the mobility of the original void-filler and its adjustment to pressure-temperature conditions. The effective porosity/depth relationship for shales (Gussow, 1955) and for the sandstones and shales of units M and P are compared in figure 1. It is probable that the addition of authigenic cementing media and that the replacement phenomena in the silty sandstones of unit P contribute to render their porosity as low or lower than that of a shale at the same depth. The permeability was nil or less than 4 md in 13 out of 14 samples of cores taken below 6500 feet. As pointed out by Woolley and Laws (1964) "low porosity would not be a disadvantage if long sections could be opened to production". The question, however, of the occurrence of thick sections of reservoir in the units M and P of the Geltwood Beach No.1 well is not supported by the evidence so far obtained.

Unit Gg is represented in the Geltwood Beach No.1 well by only 180 feet of sediments bearing affinities with the suite of greywacke sediments of the Mount Salt No.1 well. This fact indicates important structual variations at the time of the deposition of unit Gg. Unit Gd (3490-2960 feet) exhibits the same characters as found in other wells of the Otway Basin. It is a sandstone and minor mudstone unit with strong marine influences contrasting with the regressive facies of the next unit Gb above. The coal-bearing unit Gb, well-established over the whole Otway Basin, is represented in the Geltwood Beach No.1 well from 2960 to 1910 feet. It is unconformably overlain by the 100 feet thick unit Dd which exhibits chamosite oolite layers similar to those in wells in the Mount Salt and Port Campbell areas.

Unit Db (1810 - 960 feet) consists of clayey sands and silts and is unconformably overlain by unit Bc. Although age considerations are still debatable, the overlying glauconite horizon represents the onset of a transgressive shelf facies which culminates in the deposition of the limestones of unit Bb.

Correlation with units already encountered in the Otway Basin is well supported from the surface to unit Gd (Paaratte Fm.) included.

As far as petroleum possibilities are concerned the following observations appear to be relevant:

- the unit Gg (time equivalent to Belfast Mudstone but sandier), a possible source rock in other parts of the basin, is only 180 feet thick.

- unit J (equivalent to the Waarre Formation) is not present in the Geltwood Beach No.1 well.

- no porous sandstone bodies with strongly different facies, like those present in unit M of the Heathfield area, have been encountered.

- the low permeabilities below 6500 feet and low porosities below 9000 feet render unit P and the lower part of unit M unattractive as reservoirs. No open fractures were present.

Results of the drill-stem tests proved that fresh water or slightly salty water is present approximately down to the top of the unit M. In drill-stem test No.3 at 4982 to 5084 feet, gas with 92% methane, 1.6% ethane and 1.4% propane was obtained. Gas-cut mud and salt water were recovered from drill-stem tests in unit M at 6039 to 6081 feet.

Although shows of gas were detected further down in units M and P, the drill-stem tests at 8679 to 8783 feet did not recover any fluid.

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Appendix I

Cuttings description

15'-60'	90% greyish to dusky yellow, coarse to fine-grained calcarenite with rounded debris, foraminifera, gastropoda and shell debris. 10% light grey, well rounded, poorly sorted, v.fine to coarse, partly milky quartz grains.
60'-80'	90% yellowish grey, v.fine to coarse-grained calcarenite 10% rounded, poorly sorted quartz grains.
80'-180'	90-95% pale orange, fine to v.fine-grained calcarenite; some pinkish grey, v.fine-grained chalky limestone with dark chert. Between 5% to 10% quartz grains (cavings).
180'-350'	100% greyish pink, v.fine to fine chalky calcarenite; some chert fragments; some cavings.
350'-380'	100% greyish pink, v.fine to fine chalky calcarenite with abundant chert fragments (abundant bryozoa)
380'-490'	as above 350'-380'.
490'-600'	100% yellowish grey, v.fine to fine-grained chalky calcarenite, indurated, with some finely divided glauconite.
600'-680'	100% pinkish grey, v.fine to fine-grained calcarenite in part with abundant chert; some glauconite.
680'-800'	100% very light grey dense limestone with sponge spicules and shell debris; some fragments are chalky.
800'-900'	100% light grey to yellow grey, v.fine to fine-grade dense limestone (with spicules) and chert fragments; some glauconite.
900'-920'	100% light grey to greyish orange pink, v.fine to fine-grade dense limestone; some glauconite.
920'-930'	80% as above 900'-920'. 15% greyish pink, coarse to v.coarse, glossy quartz grains, coated with iron oxide. 5% pale yellowish-green, v.fine-grained glauconitic rock.
930'-970'	95% light olive-grey to pale yellowish-green (5Y6/1-5GY6/1)*, rounded to subrounded coarse to v. coarse, poorly sorted quartz grains; pebbles up to 1cm across. 5% brown limonitic silt and limonite fragments.
970'-1100'	85% loose subangular to subrounded, poorly sorted, coarse-grained quartz grains; granules and pebbles up to 5mm across. 15% red sands caved from above. Brown silty argillaceous matrix thought to occur but disagregated.
1100'-1200'	50% to 80% greyish brown argillaceous silt. 20% to 50% cavings.

* Munsell rock-color chart; Geol. Soc. America, New York 1963.

1200'-1220'	70% clayey siltstone with some scattered, greyish brown, subangular, coarse quartz grains. Some coal fragments. 30% cavings, mainly well cement, limestone, glauconite, chert and pyrite.
1220'-1250'	90% to 100% orange pink to pale brown, well-sorted, angular to subrounded, fine to coarse quartz grains; some grains are milky, some clear. 10% cavings at 1220'-1230'. Argillaceous matrix inferred.
1250'-1290'	100% orange-pink to pale brown, well-sorted, angular to rounded, coarse to v. coarse quartz grains (some milky grains with kaolinite inclusions and pyrite) some feldspar; some argillaceous matrix; few cavings.
1290'-1300'	95% orange pink to pale brown, poorly sorted, angular to subrounded, coarse to v.coarse quartz grains with kaolinite inclusions; 5% grey limestone cavings.
1300'-1340'	85% to 98% greyish pink, angular to subrounded, coarse to v.coarse quartz grains with kaolinite inclusions; some feldspar. Up to 10% reddish brown sideritic rock fragments with flakes of carbonaceous matter. 2% to 5% cavings.
1340'-1480'	90% to 100% pale orange to yellowish brown, moderately sorted, subangular to subrounded, coarse to medium quartz grains with kaolinite, and some chloritic inclusions. 10% cavings. Some clay - silt matrix inferred. At 1440'-1450' some coal fragments.
1490'-1500'	100% dusky yellow brown, poorly sorted sandstone. Some matrix: dark argillaceous matrix with abundant pyrite.
1500'-1710'	100% pale brown to pale orange (10YR8/2) mudstone with scattered medium to coarse quartz grains; some grains are milky and with kaolinite inclusions; some sideritefragments; some dark carbonaceous matter.
1710'-1740'	80% to 90% pale brown to greyish orange mudstone with scattered quartz grains; some silty chloritic cement; about 10% pure yellowish-brown siderite with carbonaceous flakes.
1740'1840'	40% to 80% sandy mudstone with subangular to rounded, coarse to v.coarse quartz grains. 20% to 60% yellowish orange to greyish orange sideritic sandy siltstone; some chert fragments; and some pyrite; some caved well-cement.
1840'-1850'	80% greyish orange, very sandy mudstone with about 40% angular to subrounded quartz grains with kaolinite and sideritic inclusions.
1850'-1860'	80% brick-red sandy sideritic siltstone. 15% argillaceous siltstone and sandy mudstone. 5% cavings; some scattered quartz grains with red inclusions.

1860'-1900'	90% to 100% brown silty argillaceous sandy mudstone with pale yellowish brown, angular to subrounded quartz grains with kaolinite inclusions; up to 10% cavings.
1900'-1910'	20% as above 1860'-1900'. 80% vivid orange to dark yellowish orange sandy sideritic rock with limonite pellets; some pyrite; some red siderite with phosphate reaction.
1910'-1940'	10% to 80% dark yellowish brown sands with clay incrustations related to lithology 1860'-1900'. 20% to 90% siderite rock fragments; abundant siliceous rocks and quartzite grains, granules and pebbles up to 5mm; some pyrite; some cavings.
1940'-1950'	90% light olive-grey, poorly sorted, subangular to subrounded, coarse to v. coarse quartz grains; pebbles up to 6mm across and well rounded. 10% medium brown silty siderite with carbonaceous flakes (could be caved).
1950'-1960'	80% as above 1940'-1950', pebbles up to 1cm across. 15% medium to dark grey argillaceous siltstone with carbonaceous flakes. 5% cavings of sideritic rock.
1960'-1990'	80% to 100% subangular to subrounded, medium to v.coarse quartz grains. 5% to 20% medium to dark grey silt with carbonaceous matter; some pyrite.
1990'-2020'	100% medium grey, well-sorted,subangular to subrounded, medium to coarse quartz grains with traces of grey clayey silty matrix.
2020'-2080'	80% brownish grey, poorly sorted, angular to subrounded, coarse to medium quartz grains with dark brownish grey incrustations of mudstone; (about half the grains are obviously caved). 20% dark grey silty mudstone with carbonaceous flakes; some coal fragments.
2080'-2150'	70% to 90% brownish grey, well to moderately sorted, angular to subrounded quartz grains; some cavings. 5% to 30% dark grey argillaceous siltstone; some caol fragments; some pyrite; some siderite (could be caved from unit Dd - 1840 to 1910 feet).
2150'-2430'	This interval is similar to the above 2080'-2150'. Some coal fragments are scattered over the interval.
2430'-2750'	95% to 100% greyish orange-pink, poorly to moderately sorted, angular to subrounded, v. coarse to medium quartz grains with kaolinite inclusions; some grains are euhedral; few feldspars. 5% grey to greenish siltstone fragments. 2470'-2490' missing.
2750'-2940'	95% yellowish brown, poorly to moderately sorted, angular to subrounded, coarse to v.coarse quartz grains, some with kaolinite inclusions; some feldspar; 5% argillaceous silt; some pyrite.

2940'-3000'	70% to 90% loose sands as above 2750'-2940'. 5% to 10% deep red silt. Some medium yellowish dolomitic sandstone at 2975'.
3000'-3110'	50% to 95% pale brown, poorly sorted, angular to subrounded, medium to coarse quartz grains with kaolinite inclusions; some milky grains. 5% to 20% argillaceous silt with carbonaceous flakes. 5% to 30% light brownish grey, poorly sorted, angular, v.fine to coarse-grained dolomitic sandstone.
3110'-3130'	90% to 95% orange pink to pale brown, poorly sorted, angular to subrounded, v.coarse quartz grains; some milky grains, some with white and black inclusions; some feldspar. 5% to 10% light greyish brown argillaceous siltstone.
3130'-3390'	85% to 99% loose quartz grains as above 3110'-3130'. 1% to 10% argillaceous siltstone as above " 2% to 5% sandy dolomite and siderite rock.
3390'-3400'	missing.
3400'-3460'	75% orange pink to pale brown, moderately sorted, angular to subrounded, coarse to v.coarse quartz grains with grey inclusions. 10% medium olive grey argillaceous siltstone. 15% brick red sideritic silt, sandy in part; some siderite cement.
3460'-3550'	60% argillaceous siltstone with carbonaceous flakes; some coal fragments; some pyrite. 20% light brown, poorly sorted, angular to subrounded, medium to v.coarse quartz grains; some abundant milky quartz grains. 20% brick red to greyish red argillaceous sandy siderite.
3550'-3640'	80% orange pink to pale brown, poorly sorted, angular to subrounded, coarse quartz grains with kaolinite and black inclusions; some feldspar. 15% pale to greyish brown argillaceous siltstone with tiny carbonaceous flakes. 5% yellowish to medium brown sandy siderite.
3640'-3680'	60% dark yellowish brown argillaceous siltstone. 40% yellowish brown, moderately sorted, angular to subrounded, coarse quartz grains with inclusions as above 3550'-3640'.
3680'-3730'	as above only the percentages vary.
3730'-3880'	90% to 100% argillaceous siltstone in part chloritic. 5% to 10% silty to sandy siderite.
3880'-3890'	100% argillaceous silty sandstone as in intervals above.
3890'-3910'	80% dark greenish grey argillaceous siltstone. 20% pale yellowish brown sandy siderite.
3910'-3920'	40% dark grey argillaceous siltstone sandy in part (quartz grains up to coarse grade). 60% cavings.

3920'-4110'	100% yellowish brown argillaceous sandy siltstone; sandy fraction is made up of 10% poorly sorted, coarse quartz grains.
4110'-5050'	100% medium olive grey argillaceous siltstone with well-sorted, v.fine to v.coarse quartz grains; matrix: chlorite and clay. Some calcite-dolomite.
5050'-5060'	missing.
5060'-5310'	100% dusky yellowish green, well-sorted, angular, v.fine to v.coarse-grained silty sandstone.
5310'-5330'	70% to 90% pale brown to dusky yellowish green argillaceous chloritic mudstone and chloritic siltstone. 10% to 30% clear, moderately sorted, angular to subrounded, medium to coarse quartz grains; minor feldspars.
5330'-5470'	100% argillaceous siltstone as above 5310'-5330'.
5470'-5490'	90% to 95% argillaceous siltstone as above 5310'. 5% to 10% clear, poorly sorted, angular, coarse to v.coarse quartz grains.
5490'-6070'	100% light dusky yellowish green to medium brown argillaceous chloritic mudstone and siltstone. Some clear, poorly sorted, angular quartz grains at 5500'-5510'.
6070'-6080'	90% light olive grey chloritic mudstone and siltstone. 10% clear, moderately sorted, angular, coarse to v.coarse quartz grains.
6080'-6220'	40% to 90% medium olive grey chloritic mudstone and siltstone. 10% to 60% clear, moderately sorted, angular, v.coarse to coarse quartz grains.
6220'-6320'	95% chloritic mudstone as above 6080'-6220', including minor v.fine-grained sandstone. 5% clear, well sorted, angular, coarse to v. coarse quartz grains.
6320'-8300'	100% medium greenish grey chloritic mudstone, with well-sorted, angular, v.fine-grained sandstone.
8300'-8400'	90% to 95% chloritic mudstone, siltstone and sandstone. 5% to 10% brownish grey, moderately sorted, angular, medium to coarse quartz grains.
8400'-8500'	100% medium brownish to greenish grey chloritic mudstone and siltstone with well-sorted, angular, v.fine to silt-sized quartz grains. Some coaly flakes.
8500'-8540'	90% chloritic mudstone and siltstone as above, 8400'-8500'. 10% clear, well-sorted, angular to subangular, medium to coarse quartz grains.
8540'-9200'	100% medium greenish grey chloritic mudstone and siltstone with well-sorted, angular, v.fine to silt-sized quartz grains.

9200'-9330'	90% medium greenish grey chloritic mudstone, siltstone. 10% brownish grey, well-sorted, angular to subangular, medium to coarse quartz grains.
9330'9380'	100% greenish grey chloritic mudstone with well-sorted, angular, v.fine grained sandstone and siltstone.
9380'-9390'	60% greenish grey chloritic mudstone, siltstone and sandstone as above 9330'-9380'. 40% brownish grey, well-sorted, angular to subangular, medium to coarse quartz grains.
9390'-9600'	10% to 70% clear, moderately sorted, angular to subangular, fine to v.coarse quartz grains: some with white, yellowish and green inclusions; some feldspar. 30% to 90% chloritic mudstone, siltstone and sandstone.
9600'-11210'	100% greenish grey chloritic mudstone, siltstone sandstone.
11210'-11310'	60% to 95% chloritic mudstone, siltstone and sandstone. 5% to 40% coal fragments.
11310'-11900'	100% medium brownish grey chloritic mudstone, siltstone, and well-sorted, angular, v.fine-grained sandstone.
11900'-12090'	100% chloritic mudstone, siltstone and sandstone as above 11310'-11900'; minor pebbles.
12090'-12300'	100% brownish grey mudstone, siltstone and v.fine-grained sandstone.

APPENDIX 2

Core Analysis Sample Description

Core No.1 2000'-2015' Clayey sandstone
Medium grey, massive, showing conchoidal fracture. Finely micaceous and carbonaceous. Silt lenses account for porosity (30%). No permeability.

Core No.3 2328'-2340' Sandy mudstone.

Sample unreliable.

Core No.4 2651'-2652' Mudstone.

Rather massive, olive-black pyritic carbonaceous mudstone with lenses of sandstone. The sand lenses contain quartz, feldspar (7%) grains. Grain-size varies from fine to very coarse (with few granules). The matrix of the sand lenses is kaolinite and minor spots of siderite. These lenses could account for the 29% porosity figure, and the lack of interconnection explains the nil permeability.

Core No.6 3317'-3332' Siltstone and sandstone.

Pyritic sideritic siltstone with sandy lenses and laminations. Poorly sorted, angular, fine to very coarse-grained quartz and minor feldspar. The bonding material is of a clay, opaque minerals and siderite. Porosity (22%) mainly due to incomplete cementation of sandy parts. No permeability measured.

Core No.7 3632'-3647' Mudstone

Due to poor recovery, it was not possible to prepare core analysis samples nor thin-sections. The rock is a greenish grey mudstone with abundant carbonaceous flakes and a few sandy lenses, but no sedimentary structure. No core analysis made.

Core No.8 3776' Very fine grained sandstone (greywacke), bearing angular, very fine-grained rock fragments (25%), quartz (15%) and feldspar (5%) grains. Clay-chlorite-detritus matrix. Abundant carbonaceous matter and pyrite. Horizontal porosity (25%) may be due to presence of sandy laminations or lenses. Low-angle cross-bedding and minor burrowing is present. No permeability measured.

Core No.8 3778'-3779' Very fine-grained sandstone (greywacke)
Well sorted, angular, very fine-grained quartz (15%), rock fragments (25%), feldspar (5%). Silt, clay and chlorite matrix. Abundant carbonaceous matter and pyrite. Fine laminations, low-angle cross-bedding, and lenticular development of sandy parts frequent. Incomplete infilling of intergranular space in sand lenses is responsible for the porosity (28% H and V). Higher vertical permeability (42 md) than horizontal permeability (16 md) is accidental (fracture of plug).

Core No.9 4097'-4098' Chloritic sandy mudstone.

Vaguely laminated and irregularly bedded chloritic mudstone with abundant carbonaceous material, mica flakes and pyrite. Some siderite. Sand lenses contain abundant lithic fragments, feldspar and quartz grains. The incomplete matrix of chlorite, clay and opaque material in the sandy parts, is responsible for the porosity (27% V and 30% H). Permeability is very low.

Core No.10 4409'-4410' Very fine grained sandstone (greywacke) with shale laminations.

Sandy parts contain angular very fine grained rock fragments (25%), quartz (15%) anf feldspar (10%). Clayey, chloritic matrix with abundant opaque material and coaly matter. Laminations, small-scale load structures are present. Claystone pebbles observed. Subvertical roots present. Microporosity and incomplete bonding by matrix is responsible for porosity figure (28%). No permeability.

Core No.11 4513'-4514' Mudstone

Greenish grey chloritic mudstone with silt lenses. Silt lenses contain very fine quartz and feldspar grains and abundant chloritic rock fragments. Pyrite and carbonaceous matter is present. Undulate laminations, low-angle cross-bedding and scour-and-fill are common. Porosity (25% V and H) due to silt lenses. No permeability.

Core No.12 4771'-4772' Very fine grained volcanic sandstone. Moderately to well sorted, angular, fine to very fine-grained volcanic rock fragments (40%), feldspar (20%) and quartz (10%) grains. Chlorite and clay matrix. Sandy laminae may or may not have intergranular matrix. In the latter case porosity is very good (27%) and permeability varies from 107 md vertically to 212 md horizontally. The anisotropy is induced by the orientation of the detrital grains and by the presence of flaky carbonaceous material and micas.

Core No.13 5058'-5059' Very fine-grained sandstone (greywacke) Moderately sorted, angular, very fine quartz (5%), feldspar (20%) and lithic fragments (40%) Clay, chloritic and detritus matrix. Lenses with mudstone fragments (up to 3 mm across). Porosity (24%V, 26%H) due to incomplete infilling of the most sandy parts, by matrix. No permeability. Fine-lamination and low-angle cross-bedding is present.

Core No.13 5062'-5063' Similar to 5058-5059'

Lenses with abundant pebbles of mudstone induce good local permeability (20 mdV, 22 md H).

Core No.14 5333-5344' Very fine grained sandstone (greywacke) with shale laminations.

Well-sorted, angular, very fine to fine grained quartz (10%) feldspar (15%) grains and rock fragments (15%). Silt, chlorite, clay matrix with abundant mica. Incomplete infilling by matrix, in sandy parts, accounts for porosity (21% V & H). No permeability.

Laminations, undulations, low-angle cross-bedding, small scale scour-and-fill are common structures.

Core No.15 5655'-5662' Very fine grained sandstone with shale laminations. Same composition as core 14. Abundant carbonaceous flakes. Thin laminations, small-scale cross-bedding and slumping, minor burrows and plant roots are characteristic structures. Similar porosity - permeability relations to core 14.

Core No.16 6088'-6089' Very fine-grained sandstone (greywacke) with shale laminations.

Well sorted, angular, very fine-grained feldspar (20%), quartz (10%) grains, rock fragments (40%) in clay-chlorite-pyrite matrix with abundant mica and chlorite flakes.

Incomplete infilling of intergranular space by matrix accounts for porosity (22%V, 21%H) and low permeability (1 md V, 2 md H). Thin laminations are present.

Core No.17 6522'-6523' Chloritic mudstone.

Greenish grey chloritic mudstone with silt laminations. Abundant flaky material and carbonaceous matter. Rootlets are present. Silt laminae have porosity (18% V, 17% H) due to incoomplete infilling with matrix. No permeability. Laminations are present; horizontal branching rootlets recorded.

Core No.18 7033'-7034' Chloritic mudstone.

Greenish grey chloritic mudstone with thin laminations of silt. Abundant coal, mica, chlorite flakes. Porous silt laminae (17% H & V). No permeability. Thin laminations and low-angle cross-bedding present.

Core No.19 7546'-7556' Very fine-grained sandstone (greywacke). Well sorted, angular, very fine-grained feldspar (20%), quartz (10%) grains, and lithic fragments (30%). Clay-chlorite-pyrite matrix with abundant flaky material. Incomplete infilling by matrix accounts for porosity (20% V and H). No permeability. Thin laminations, undulations, low-angle cross-bedding are present.

Core No.20 8047'-8048'. Very fine-grained sandstone (greywacke) Well sorted, angular, very fine-grained feldspar (20%), quartz (10%), grains, and lithic fragments (25%). Clay-chlorite-detritus matrix. Abundant pyrite and flaky material (carbonaceous matter, mica). Rock similar to Core 19 but further obliteration of porosity (12%V, 14% H) is due to development of zeolite. Thin lamination and low-angle cross-bedding is present. Plant roots (partly replaced by barite) observed.

Core No.21 8479'-8480' Very fine-grained sandstone (greywacke) and siltstone. Well sorted angular very fine feldspar (25%), quartz (5%) grains and rock fragments (30%). Clay-chlorite-silt matrix. Incomplete infilling of intergranular space by matrix is responsible for porosity (14% V and H). No permeability.

Thin laminations and low-angle cross-bedding present.

Core No.22 8942'-8943' Very fine-grained sandstone (greywacke) and silt laminations.

Similar to Core No.21. Some development of zeolite depresses the porosity (11% V and 12% H) as compared with the previous sample. Horizontal permeability (8 md) cannot be explained but only related to the abundance of flaky material. Thin laminations, undulations, low-angle cross-bedding, small scale scour-and-fill structures and slumping are present. Some roots and rootlets are recorded.

Core No. 23 — 9365-9366'. Very fine-grained sandstone (subgreywacke) with calcite and zeolite cement (in part). Well sorted, angular, very fine-grained feldspar (20%), quartz (10%) and rock fragments (35%). Abundant heavy minerals. Clay and chlorite matrix in part. Most abundant is zeolite and calcite (in places clearly replacing the zeolite) cement. Strong cementation responsible for negligible porosity (2% V and 1%H) and for absence of permeability. Faint laminations are the only sedimentary features.

Core No. 24 — 9857'-9867'. Shale (silicified). Silt-sized quartz, feldspar detritus in tight groundmass of clay, chalcedony and authigenic chlorite with abundant flaky material. Slight development of zeolite. Porosity negligible (2% V, 1%H); no permeability.

Core No. 25 — 10323-10324'. Shale. Similar to core No. 24. No apparent development of chalcedony and zeolite. Low porosity (6%V and H). No permeability. Laminations, undulations, low angle cross-bedding and micro-faulting present.

Core No. 26 — 10782-10783'. Interlaminated shale and sandstone. Sandy laminae contain angular, very fine-grained lithic fragments (35%), feldspar (15%) and quartz grains. Clay and chlorite matrix with strong development of silica. The groundmass of the shale laminae is made of clay, chlorite and detritus with abundant flaky material: mica, chlorite, carbonaceous matter. Low microporosity (9%V? and 7% H). No vertical permeability. Horizontal permeability is 4 md, but fine horizontal fracture is present. Laminations, low-angle cross bedding, undulations, small scale slump structures are present.

Core No. 27. — 11236-11237' Interlaminated shale and sandstone. Sandy laminae contain angular, very fine rock fragments (35%), feldspar (20%), and quartz (15%) grains. Clay and chlorite matrix. The groundmass of the shale laminae is made of clay, chlorite, detritus and abundant flaky material. Low micro-porosity (7%V, 8%H). Thin laminations, undulations, low-angle cross-beddings are present.

Core No. 28 — 11742'-11743'. Interlaminated sandstone and shale. Sandy laminae contain angular very fine rock fragments (20%), feldspar (15%), and quartz (10%) grains. Clay and chlorite matrix. The groundmass of the shale laminae is made of clay, chlorite, detritus and abundant flaky and opaque material. Low microporosity (7%V, 8%H). No permeability. Laminations, low-angle, cross-bedding, small scale scour-and-fill present.

Core No. 29 — 12223'. Interlaminated sandstone and shale. Sandy laminae contain angular very fine rock fragments (35%), feldspar (20%) and quartz (15%) grains. Clay and chlorite matrix. The groundmass of the shale laminae is made of clay, chlorite, detritus and abundant flaky material: mica, chlorite and carbonaceous matter. Low microporosity (4%V, 6%H). No vertical permeability. Horizontal permeability is 4 md but fine fracture is recorded in horizontal plug.

Note: Vertical porosity (V) stands for porosity of vertical plug. Horizontal porosity (H) stands for porosity of horizontal plug.

Lat: 37° 39' 44" S.
Long: 140° 14' 35" E.
Elevation: (G.L.) 15·03 feet above mean sea level, Port Adelaide.
(K.B) 30·03 feet " " " " " " "
Scale: 1" = 100 ft.
B.M.R. Index No. 37

COMPOSITE WELL LOG

GELTWOOD BEACH No. 1

PLATE 1
(SHEET 1)

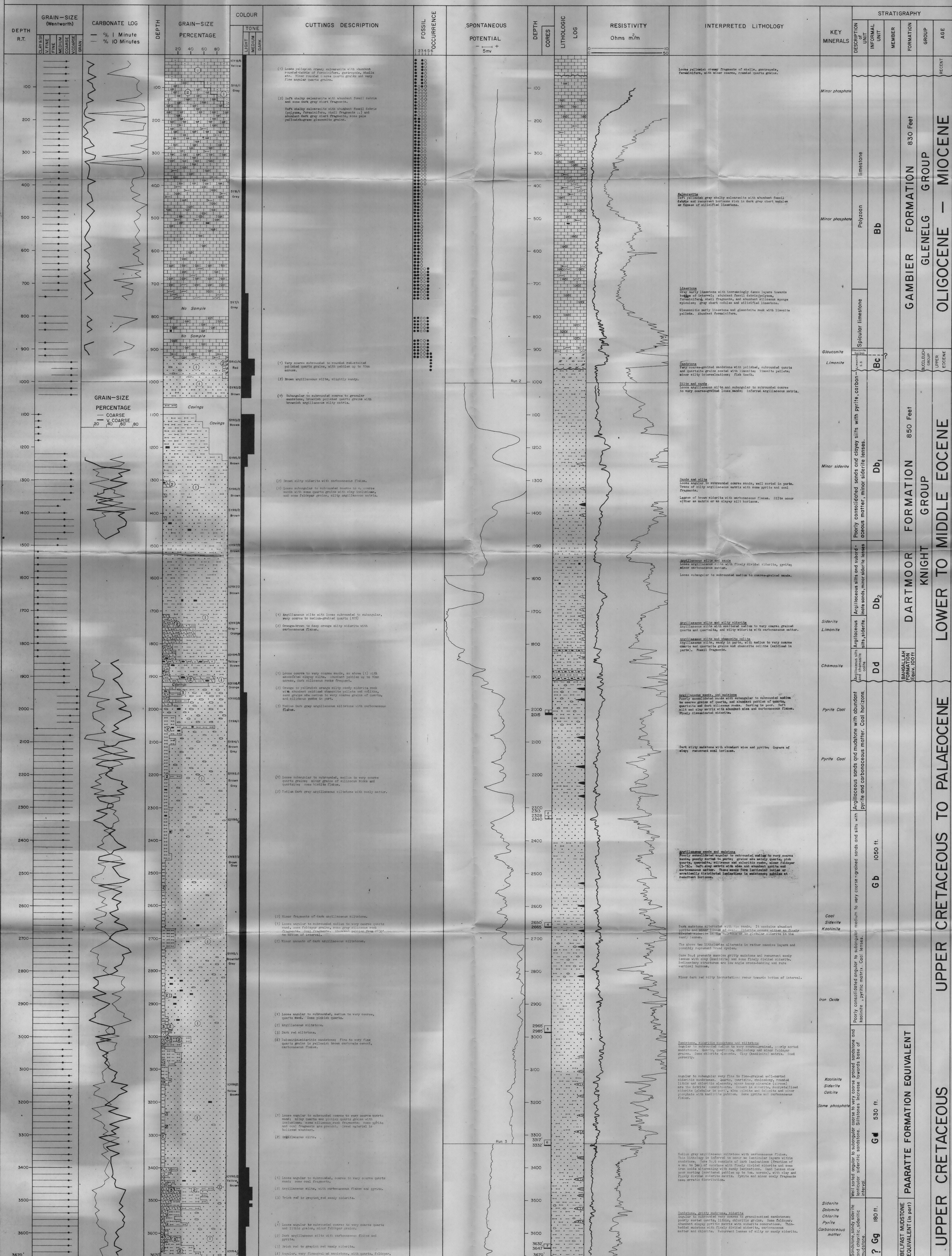
Company: BEACH PETROL. N.L.
State: SOUTH AUSTRALIA
Basin: OTWAY.

LEGEND

CONGLOMERATE · SANDSTONE · SILTSTONE · CLAYSTONE
MARL · LIMESTONE · DOLOMITE · SIDERITE
SANDY LIMESTONE OR CALCAREOUS SANDSTONE · SANDY DOLOMITE OR DOLOMITIC SANDSTONE · SANDY SIDERITE OR SIDERITIC SANDSTONE · SEAM OR LENS FRAGMENTS COAL
SKELETAL DEBRIS · GLAUCONITE · GYPSUM · PELLETS
OOLITHS · CHERT · LIMONITE · PYRITE
COAL · PHOSPHATE

FOSSIL OCCURRENCE
1. Foraminifera
2. Polyzoa
3. Shell debris
4. Gastropoda
5. Spicules
6. Fish teeth

FOSSIL ABUNDANCE
○ Present
● Abundant



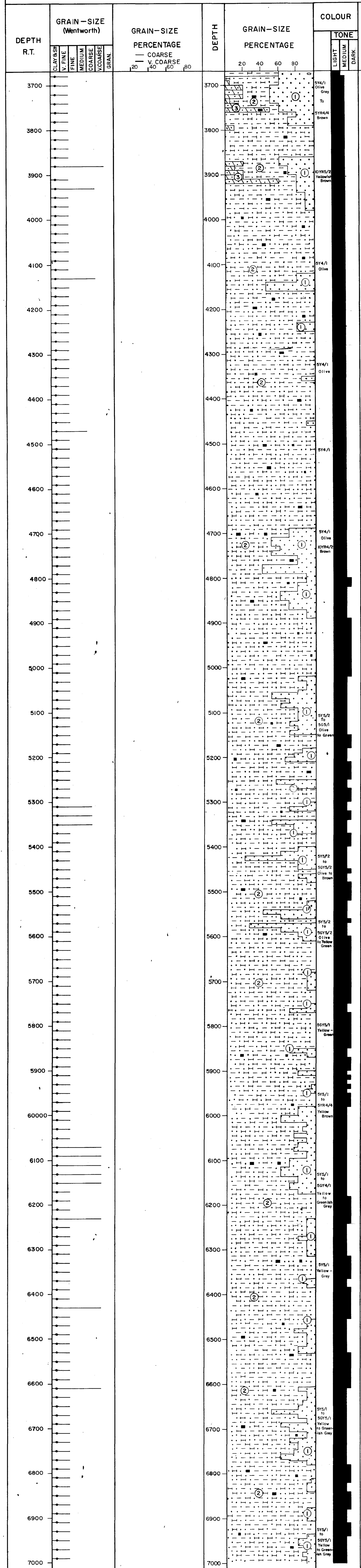
Geologists: J. DELLENBACH I.F.P.

Drawn by: G.J. SQUIRE B.M.R.

MARCH, 1965

To accompany Record No. 1965/41

PLATE 1
(SHEET 2)



CUTTINGS DESCRIPTION

(1) Loose sands mostly caved, but also comprising angular very fine-grained feldspathic lithic sandstone chips. Lithic fragments (40%) are mostly of volcanic origin.

Feldspar (albite, oligoclase, sanidine, anorthoclase) (20%). Quartz is subordinate (5-10%). Matrix is chloritic or replaced by calcite.

(2) Sandy, silty chloritic mudstone with siderite.

(3) Brownish grey to brick-red silty siderite with carbonaceous flakes.

(1) Angular very fine-grained feldspathic lithic sandstone. Lithic fragments (30%), feldspar (15%), quartz (10%) rounded fragments of chloritic matter. Replacement calcite cement.

(2) Argillaceous chloritic siltstones, very finely sandy in part, recurrent chlorite rich horizons; abundant pyrite and finely divided carbonaceous mate ial.

(3) Reddish brown sandy siderite with carbonaceous flakes.

(1) Angular very fine to fine-grained feldspathic lithic sandstone; lithic fragments (35%) are mainly volcanic rocks (partly chloritic). Feldspar is abundant (20%): oligoclase and albite. Quartz is subordinate. Cementing media are chlorite, and calcite with zeolite at 4130'.

(2) Silty chloritic mudstone, very finely sandy in parts; recurrent chlorite-rich horizons; minor amounts of angular to subrounded coarse-grained quartz: abundant pyrite and finely divided carbonaceous material.

(1) Angular very fine-grained feldspathic lithic sandstone. Abundant lithic fragments (30%): mostly aphanitic rock fragments, acid feldspar (15%) and quartz (5-10%). Abundant chlorite and mica flakes. Chlorite coating and clay-chlorite-silica matrix, slightly sideritic; increased clay matrix in parts; minor loose quartz grains and coal fragments; abundant pyrite and finely divided carbonaceous matter.

(2) Chloritic, slightly sandy mudstone with pyrite and mica and abundant finely divided carbonacecus matter.

(1) Angular very fine-grained feldspathic lithic sandstone. Abundant lithic fragments (30%), feldspar (20%), subordinate quartz. Cementing media are chlorite and or some replacement calcite.

(2) Chloritic, slightly sandy mudstone with pyrite and mica and abundant finely divided carbonacecus matter.

(1) Angular, very fine-grained, feldspathic and lithic sandstone, well-sorted in part. Lithic particles are mainly fragments of volcanic rocks, chloritic in part (15%), cryptocrystalline siliceous rocks (10%). The feldspars make up to (20%) (albite, oligoclase, and alkali feldspar).

Abundant mica (biotite and muscovite) and chlorite. Cementing medium is either diagenetic calcite or silty-clayey-chloritic matrix; minor medium to coarse loose quartz grains. Some coaly matter and pyrite. Some mudstone pebbles.

(2) Chloritic mudstone and siltstone. Some fragments are rich in brown chlorite.

Mica, pyrite and coaly matter is present throughout.

(1) Angular, fine to very fine-grained feldspathic and lithic sandstones, well-sorted in part. Lithic particles are volcanic rocks (cryptocrystalline siliceous rocks, chloritic rocks, opaque fragments) and some elements of possible metamorphic origin (chalcedony, quartzite). Untwinned feldspar, albite, oligoclase (15%) are predominant over quartz. Cementing medium is dominantly pure diagenetic calcite which forms up to 50% of the rock.

(2) Chloritic mudstone and siltstone with abundant pyrite coaly matter and mica. Minor recurrent fragments rich in brown chlorite, hence more brownish.

(1) Angular, very fine-grained feldspathic and lithic sandstone, well-sorted in part. Lithic constituents (up to 30% of whole rock) are mainly cryptocrystalline and chloritic volcanic rocks. Feldspar (15%) is acid plagioclase and untwinned as above, quartz is subordinate. Cementing media are either diagenetic calcite or clay-chlorite-silica matrix. In this case development of authigenic chlorite and mica is common, together with occurrence of recrystallized clay.

(2) Chloritic mudstone and siltstone as (2) above. Recurrent samples with abundant brown chloritic mudstone fragments.

(1) Angular very fine-grained feldspathic and lithic sandstone, well-sorted in part. Lithic constituents (up to 40%) are as above: mainly cryptocrystalline siliceous rocks and chloritic rock fragments of possible volcanic origin. Feldspar (20%) is untwinned feldspar, albite and oligoclase. Quartz is subordinate (about 10%). Mica and chlorite (partly altered or partly replacing feldspar) are abundant. Bonding media are diagenetic calcite, minor quartz overgrowths (with grain welding), chalcedony, chlorite or clayey chloritic silty matrix. Some loose clear angular coarse to very coarse quartz and feldspar grains (cavings?)

(2) **Chloritic mudstone and siltstone as (2) above. Clay is illitic and in part recrystallized with feldspar and quartz shreds.**

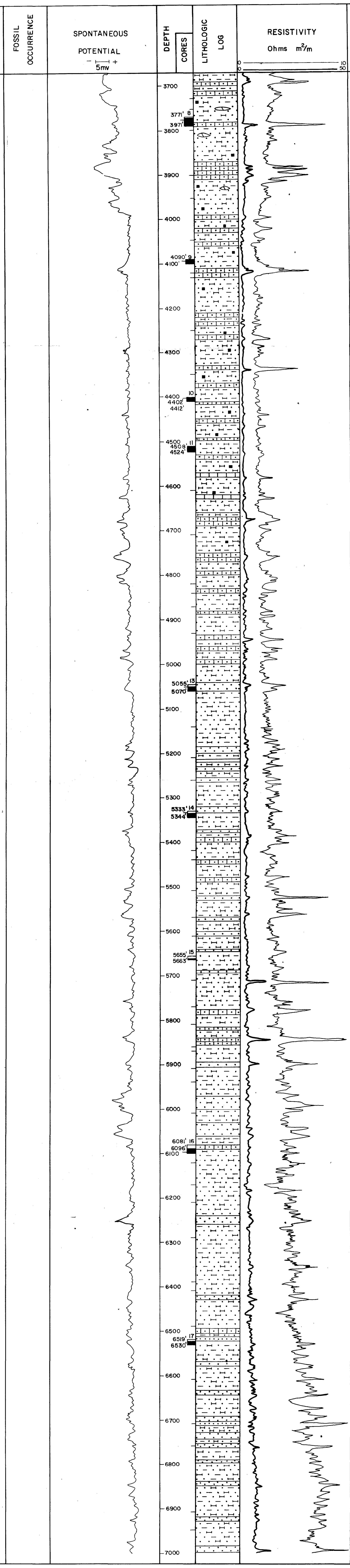
(1) Angular very fine-grained feldspathic and lithic sandstone moderately to well-sorted lithic fragments (up to 40%) are either cryptocrystalline siliceous rocks or volcanic rock fragments (basaltic, microlitic volcanic rocks, chloritic and opaque in part). In this case quartz grains are rare. Feldspar is abundant (20%) either as untwinned feldspar or as albite-oligoclase and some anorthoclase. Abundant chlorite and mica. Cementing media are silt, impure chlorite and illitic and kaolinitic clay and also pure chlorite.

(2) Chloritic mudstone and siltstone as (2) above with carbonaceous flakes and pyrite.

(1) Angular very fine-grained moderately to well-sorted feldspathic and lithic sandstone. Lithic fragments are mostly cryptocrystalline siliceous rocks and chloritic rocks (30%), feldspar (15%) and quartz (10%). Minor heavy minerals are garnet, epidote and zircon. Chlorite fragments are often squeezed. Cementing media are clay-silt-chlorite and some silica (including quartz with grain welding, and solution features also affecting feldspar).

(2) Chloritic mudstone and siltstone as (2) above, carbonaceous flakes and pyrite. Siderite-rich fragments.

FOSSIL OCCURRENCE



INTERPRETED LITHOLOGY

Chloritic mudstone and fine-grained sandstones
Yellowish green chloritic mudstone and angular very fine-grained sandstones ranging from greywacke composition to volcanic sandstones. Lithic fragments (up to 40%) are volcanic rock fragments, chloritic rocks, and metamorphic rock fragments. Abundant feldspar (15-20%): sanidine and acid plagioclase; subordinate quartz (5-10%). Cementing media are primary pellicular chlorite, clay-chlorite-silt matrix or replacement calcite. Some recrystallized clay of the kaolinite group is also present. Siderite is present. These two lithologies alternate in thin laminations outlined by carbonaceous and mica flakes as shown by core 8, and show low angle cross-bedding, and layers with abundant chloritic mudstone pebbles. Intense churning and burrowing.

Chloritic mudstone and very fine-grained sandstones
Yellowish green to olive-coloured chloritic sandy mudstone with abundant pyrite, mica, and flakes of carbonaceous matter. Detrital elements are very fine-grade angular lithic fragments, chloritic in parts, and feldspar. Minor scattered quartz and quartzite grains occur throughout. At 4090-4100', core 9 presents this type of rock with thin laminations, disturbed bedding, abundant traces of rootlets and minor burrowing.

Angular very fine-grained sandstones varying from greywacke and subgreywacke to volcanic sandstones. Lithic fragments (30-35%) are aphanitic rocks and/or volcanic rock fragments (microlitic rocks, chloritic rocks). Feldspar (20%) is untwinned feldspar and acid plagioclase. Quartz occur in varying amounts (10-20%) but always subordinate to lithic fragments. Hornblende occurs in a volcanic sandstone at 4119'. Cementing media are either chlorite, clay, and ~~silt,~~ or replacement calcite. Minor zeolite (subisotropic type) occurs at 4130'. Pyrite, mica and carbonaceous flakes are present throughout.

At 4402-4412', core 10 shows the mudstone and sandstone either finely interlaminated or with more massive aspect; low angle cross-bedding occurs, and claystone pebbles are present.

There is evidence for roots, and compaction and load features exist between mudstone and sand layers.

At 4508-4524' core 11 consists of chloritic mudstone with silty, very fine sandy lenses; undulate laminations and disturbed bedding together with low angle cross-bedding, scour-and-fill structures and mudstone layers with mudstone pebbles are present. Pyritic nodules are present.

At 4770-4780' core 12 presents fine-grained lithic sandstone rich in volcanic fragments with chloritic pellicular cement (with fair porosity). Fine laminations and low angle cross-bedding occur together with layers rich in mudstone pebbles. Some chloritic mudstone shows roots in growth position. Cores 9 to 12 are representative of the lithology over the interval.

At 5055 to 5070' core 13 presents a rather massive, medium dark, greenish, angular, very fine-grained sandstone with very thin laminations of coaly matter and layers rich in mudstone pebbles. Lithic fragments are abundant (25% or more) and mainly chloritic volcanic rock fragments. Feldspar (15-20% is untwinned feldspar and acid plagioclase. Quartz is subordinate. Matrix is variable in amount and made of chlorite (authigenic in part) and recrystallized? clay (kaolinite group).

Chloritic mudstone and very fine-grained sandstones
Greenish grey to brownish chloritic mudstone with mica and abundant pyrite and coaly matter.

Angular, very fine-grained sandstones varying from greywacke to volcanic sandstone. Predominant volcanic elements between 5400 and 5600' and possibly towards base of interval. Overall average content of lithic fragments is 30%, predominantly of volcanic origin. Feldspar is acid plagioclase or untwinned feldspar (15-25%). Quartz is subordinate (5-15%). Chlorite occurs both as detrital material and as authigenic cement. Mica (biotite mainly) is abundant and partly chloritized. Cementing media are clay and chlorite matrix with silty detritus and some cryptocrystalline silica. Recurrent horizons are cemented with zeolite minerals. Clean recrystallized kaolinite group clay mineral is present in some horizons. Calcite is a replacement mineral in many instances.

Core 14 presents thin silty laminations, flat-lying or undulating, showing scour-and-fill and low angle cross-bedding. Flat-lying plant elements (rootlets?) at 5342'.

Core 15 also shows laminations, low angle cross-bedding, contemporaneous slumping, and a good example of a vertical burrow, 3mm in diameter and 7 cm long at least.

These lithological characters are assumed to be represented throughout the interval. Some cuttings show thin laminations and a few intraformational rounded mudstone fragments.

The frequency of strongly cemented horizons-presumably by calcite-increases towards bottom of interval.

Chloritic mudstone and very fine-grained sandstones
Greenish grey to brownish chloritic mudstone with mica and abundant pyrite and coaly matter. Minor erratically distributed subrounded coarse to very coarse quartz grains throughout.

Angular very fine-grained sandstones varying from greywacke to volcanic sandstone. ~~Lithic elements~~ vary in amount from 20 to 40%. Aphanitic rocks fragments of probably volcanic origin are predominant but low grade metamorphic rocks are widely present. Feldspar (15-25%) is acid plagioclase, untwinned feldspar (some zoned) and minor anorthoclase. Quartz is subordinate (5-10%), At 6700', a good example of volcanic sandstone or even microbreccia occurs. Cementing media are: silt, clay and chlorite with possibly some cryptocrystalline silica and zeolite. Clean pellicular or scaly chloritic-illitic material and clean recrystallized clay material of kaolinitic composition are also present. Replacement calcite frequent. Zeolite-bearing sandstones recur over the interval. Towards base of interval, detrital grains are increasingly welded, interpenetrated and overgrown.

Heavy minerals are rare and homogeneously distributed throughout: apatite, epidote, garnet, sphene, zircon.

Core 16 and core 17 display rather massive claystones and sandstones with thin undulating laminations, low angle cross-bedding, and small scale slump structures. Plant roots and rootlets are present. These types of sediments are thought to recur throughout the interval.

KEY MINERALS

Chlorite
Kaolinite
Calcite
Siderite

Chlorite
Zeolite
Kaolinite group
Clay
Calcite
Pyrite
Coally matter

Chlorite

Chlorite

Zeolite
Zeolite
Zeolite
Zeolite
Zeolite
Zeolite
Zeolite
Zeolite
Zeolite
Zeolite
Zeolite
Zeolite
Zeolite
Zeolite
Epidote

STRATIGRAPHY

DESCRIPTION of UNIT | INFORMAL UNIT | MEMBER | FORMATION | GROUP | AGE

Chloritic sideritic mudstone and very fine grained lithic feldspathic sandstone with chlorite, calcite and siderite.

Chloritic mudstone and angular, very fine-grained, well sorted sandstone, with abundant lithic fragments and feldspar. Volcanic sandstone at 4120 feet. One crystalline zeolite horizon at 4120 feet. Elsewhere clay, chlorite, calcite cements.

Chloritic mudstone and angular very fine-grained, well sorted sandstones with abundant lithic fragments and feldspar. Abundant volcanic elements between 5400 and 5600 feet. Frequent ill-crystallized zeolite cement, chlorite, clay and calcite.

Chloritic mudstone and angular very fine-grained, well sorted sandstones. Abundant lithic fragments and feldspars. Cementing media are illite, kaolinite, chlorite, crystalline zeolite. Increase of compaction with pressure solution phenomena at bottom of interval.

M

MERINO GROUP

ALBIAN — CENOMANIAN

To accompany Record No. 1965/41

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PLATE 1
(SHEET 3)

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