COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1965/76

A PETROLOGICAL STUDY OF THE SEDIMENTS FROM FROME-BROKEN HILL EUMERALLA No. 1 WELL, OTWAY BASIN, VICTORIA.

by

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ABSTRACT

The relatively large thickness of the Eumeralla No. 1. sediments compared with those of nearby Pretty Hill No. 1 well, (Edworthy, 1964) appears to have been the result of movement of an E-W normal fault with southerly downthrow (south of Pretty Hill No. 1. and north of Eumeralla No. 1.) during pre-Upper Cretaceous times. Unit P represents an interdigitation of unit M sediments, with sediments showing resemblance to unit R (protoquartzitic sandstone described from Pretty Hill No. 1. well) and unit M (Otway Group equivalent).

Unit M is a uniform succession of volcanic sandstones, subgraywackes, chloritic siltstones and claystones.

Unit Bc is developed (160 feet); unit Dd is present and unit Gb is of small thickness. No evidence for unit Gh was discovered. The unconformity between unit M and the Upper Cretaceous present in much of the basin was not recognised.

In the absence of other criteria, the cementing media of unit M have been closely studied in an effort to establish subdivisions. Chloritic, kaolinitic clay, and zeolitic types of cement were observed, the zonation of the various types of cement in the sequence bearing similarity to those established in Geltwood Beach No. 1 and Heathfield No. 1. Authigenic sphene occurs in the deepest part of the sequence, (below 9,800 feet).

Some porous and permeable horizons exist above 6,000 feet in unit M, and also in unit P. Porosity is high and permeability is generally nil throughout the Lower Cretaceous. Primary porosity is infilled with products of diagenesis in many cases especially below 6,500 feet (see Fig. 1.)

INTRODUCTION

The Eumeralla No.1 well was drilled for Frome-Broken Hill Pty Ltd, approximately 10 miles west of the Pretty Hill No.1 well, and approximately 8 miles east of Tyrendarra. Details of the well, and its location are given below.

Location. - Latitude 38°12'43" S.
Longitude 141°56'01" E.

Reference on 1 mile military map of Heywood: 895885
1:250,000 sheet. Portland No.J.54-11

Total depth = 10,308 feet.

Elevation Ground level - 154 feet A.S.L.
Datum level (R.T.) - 167 feet A.S.L.

The cost of the drilling operation was subsidised under the Petroleum Search Subsidy Act, 1959-61.

Samples of all cuttings collected, and approximately 14% of cores taken, were available for examination, and thin-sections were made where considered necessary.

The composite-log and the well-completion report (F.-BH., 1963) were the principal references used in studying the well.

The two main purposes of the study were,

(i) To investigate further, the petroleum possibilities of the Tyrendarra embayment; and

(ii) advancement in the work of compiling a sedimentary history of the Otway Basin.

Some important differences from the sequence intersected in Pretty Hill No.1 Well were encountered.

Unit P

The upper boundary of the unit has been placed at 9,110 feet. Five intervals of high resistivity and marked S.P. deflection occur within the interval, and these mark the positions of the coarsest sandstones. The resistivity of the whole sequence is relatively high.

Cuttings are of hard, light to medium-grey sandstones and siltstones; the coarsest sandstones are v. light grey. Cores 22 to 25 were taken within the unit, and all cores except core 23 (9767-69 ft.) show small scale cross-bedding and some scouring. Cores 24 and 25 (9881-83 ft, 10300-02 ft.) show some penecontemporaneous deformation structures, and core 23 shows faint root traces. Most samples are thinly-bedded and all are carbonaceous to some degree, the carbon being finely disseminated or in fine lenses and interlaminae. Dip is uneven and of low angle (less than 20°). Almost vertical fracturing is present in most core samples.

In Pretty Hill No. 1 well, the basal sandstone (unit R) was found to possess the follrwing properties:

(i) conspicuous garnet,

(ii) the feldspar fraction contains over 50% microcline, and plagioclase is rare or absent,

(iii) poor sorting and maximum grain size of up to 2mm.,

(iv) bedding features produced in an environment of relatively high energy,

(v) quartz and metaquartzite grains are dominant and labile lithic grains are rare.

The above features are clearly represented toward the base of the Eumeralla well section. Initiation of these trends is suspected to occur at a slightly higher horizon than 9110 feet but sampling is not sufficiently adequate to define the upper boundary or the unit more precisely.

Thin-section studies reveal that the rocks of unit P are hybrid types which exhibit features of both units R and M. For instance, a certain amount of volcanic rock grains and abundant biotite flakes, typical of unit M, are present in the sections examined, and other unit R characteristics assert themselves strongly enough throughout to make the affinities of the unit unmistakeable. The sandstones are generally angular to subrounded, fine to coarse-grained, poorly sorted subgraywackes* and volcanic sandstones*. Quartz together with metaquartzite and chert varies from 5% to 45% of the total rock. Lithic grains vary between 10% and 70% in abundance; these are dominantly of volcanic origin and vitreous (?)rhyolitic, or tuffaceous (?)dacitic or andesitic and other rarer types. A fragment of radiolarite was found in the thin section from cuttings between 10,040-50 feet, and a (?)variolitic basalt grain in the thin-section of cuttings from between 9170-200 feet. Feldspar may constitute up to 30%, chiefly untwinned feldspar and sodic plagioclase, but also conspicuous microcline.

The argillaceous rocks are abundantly chloritic** and illitic** and show no clear differences from those of Unit M.

Pink garnet is particularly abundant (up to 3%) in rocks which show the most pronounced unit R characteristics. Zircon and epidote also appear as detrital grains.

A variety of diagenetic changes have occurred in unit P and there is a corresponding variety of cementing media. These are set out below -

(i) Chlorite

(ii) Zeolite

(iii) Kaolinitic clay

(iv) Calcite

(v) Sphene

(vi) Leucoxene

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* The above terms "subgraywacke" and "volcanic sandstone" which are used throughout are those defined by Pettijohn (1957) and Williams, Turner & Gilbert (1955) respectively.

** The terms "chloritic" and "illitic" are used in a general sense and are not intended to be specific.

Chlorite occurs throughout unit P in Eumeralla No. 1 either as a cement or as an alteration product of the lithic grains. In many cases the chlorite, which varies from green to brown in colour, coats the grains and in some cases shows "chevaux de frises"* form. In the finer-grained sandstones and siltstones the chlorite appears to be amorphous or finely crystalline, perhaps replacing a primary matrix. Brown chlorite occurs as cement in thin-sections at 9,700 -10 feet and 10,220-30 feet.

Zeolite which is very abundant as a cementing medium throughout unit P, bears an ophitic** relationship to the clastic grains and greatly reduces any primary porosity. The zeolite pore-filling is commonly surrounded by "chevaux de frises" chlorite. Feldspars are extensively replaced by the zeolite. The zeolite is uniaxial negative, colourless, and shows good cleavage in one direction.

Kaolinitic clay mineral occurs in samples thin-sectioned from 9,100 - 200 feet, and 9,300 -400 feet, replacing both interstitial matter and detrital grains.

Calcite occurs in almost all sections examined and may exist as either very small patches, or up to 60% of the rock, replacing both feldspars and many labile lithic grains as well as interstitial material, whether cement or matrix.

Below 9,700 feet, a light brown, slightly pleochroic mineral occurs in pore spaces and replacing detrital grains. The mineral which has high relief and high birefringence, amounts to approximately 5% in many cases (e.g. cuttings thin section, 9,870 - 80 feet), and has been tentatively identified as sphene. It is clearly authigenic in origin.

Leucoxene, easily visible in reflected light appears as an alteration product of many of the volcanic grains. It appears as a fine white powder distributed over the iron-rich grains, and is very common.

The fractures observed in cores taken in unit P (see page 1) have no effect on the values of porosity and permeability obtained by the Petroleum Technology Section (see Appendices 2 and 3). The presence of fracturing however suggests the possibility that fracture porosity may be effective elsewhere in the basin.

The coarse grained intervals of unit P, which show greatest affinity to unit R of the Pretty Hill No. 1 well produce clear deflections in the S.P. curve. Core 24 is an example of this lithology, which shows relatively good porosity and permeability (see Appendices 2 and 3; also Fig. 1). The intervals appear to merit

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*The term "chevaux de frises" used in the text describes the habit of the chlorite coating clastic grains; "....a radiating halo formed by fine, green platelike and acicular crystals of chlorite...." (Carozzi, 1960).

**The relation between the zeolite cement and the clastic grains is most akin to that between pyroxene and plagioclase in an igneous rock of ophitic texture.

further study as possible stratigraphic traps, since they most probably thin-out and disappear to the west of Eumeralla No. 1. No drill-stem tests were made below 8700 feet.

The microfossils of the sequence provide evidence that the well bottoms in Lower Cretaceous sediments (i.e. the association of Cicatricosisporites dorogensis and Aequitriradites verrucosus in core 25, Evans, 1963). Evans also points out that core 20 (7200-14 feet) in Pretty Hill No. 1, (i.e. unit R) contains a possible Upper Jurassic assemblage which could be as old or older than the assemblage at the bottom of Eumeralla No. 1.

Unit M

Argillaceous rocks are dominant in this unit. Sandstones contain much volcanic material, and some are volcanic sandstones; sandstones of subgraywacke type are however most abundant. Subdivision based on cementing media, established from thin-section study, is supplemented by the electric logs in the subdivision made below.

Interval 9,110 - 8,400 feet The interval is characterised by uniform S.P. and high to very high resistivity with numerous peaks, which are most conspicuous between 8,600 and 8,800 feet.

Argillaceous rocks predominate over poorly sorted, very fine to medium-grained volcanic sandstones, and several coal horizons occur. In cuttings samples, the lithology is dark grey, light grey or slightly greenish grey. Coal is most abundant in cuttings between 8,500 - 8,600 feet and 8,700 - 8,800 feet.

Cores 20 (8,459 - 65 feet) and 21 (8,914 - 24 feet) were taken from within the interval; these are of grey, and greenish grey sandstones, showing fine lamination, abundant flakes and lenses of carbonaceous material, and small-scale cross-bedding. Broken and deformed siltstone laminae, (Core 20, 8,461 - 63 feet), mud pellets (Core 21, 8,914 - 16 feet), and much penecontemporaneous deformation (Core 21, 8,918 - 20 feet) is visible. Both cores contain several thin calcareous horizons.

Illite, kaolinitic clay and abundant chloritic material are the chief constituents of the argillaceous rocks, with patches of (?) zeolite. Zeolite which is present in the arenacous rocks may exist in a cryptocrystalline state throughout the argillaceous rocks. Carbonaceous flakes are also abundant.

The sandstones are poorly-sorted, angular to subrounded very fine to medium-grained, and contain up to 65% volcanic rock fragments. Feldspar (up to 25%) is commonly more abundant than quartz (up to 20%).

(?)Dacitic and (?)andesitic fragments, tuffaceous rocks, devitrified glass, very minor metaquartzitic grains and some (?) chert constitute the lithic grains. The feldspar fraction is of sodic plagioclase, orthoclase, and very minor microcline; grains are commonly angular and in some cases euhedral, and there is generally some calcitization. Quartz is very angular and some rare grains have iron-oxide coatings. Most of the thin-sections examined are of volcanic sandstones; some very fine-grained sandstones with more than 15% matrix are more aptly termed lithic graywackes.

Biotite and white mica (either bleached biotite or muscovite flakes) are abundant, especially in carbonaceous laminae. Epidote, zircon, (?)apatite, garnet and opaque minerals also occur as heavy minerals.

Porosity is very low in the cores (between 2 and 3%) and permeability nil. Drill-stem tests 3 and 4 were made between 8,653 and 8,718 feet, but in both cases, the packer failed to hold. At several horizons gas was detected in the mud, but on each occasion the gas appears to have been associated with coal stringers.

Cementation and palaeontology are discussed on pages 7 - 9.

Interval 8,400 - 6,000 feet

The top of the zone of conspicuous resistivity maxima is regarded as the lower boundary of the interval. The top boundary is marked by the appearance of abundant zeolite. Resistivity logs show a zone of maxima between 6,650 - 7,300 (0-200 sensitivity). At the top of the above interval, there are several peaks in the S.P. curve, relative to the shale base-line.

Cuttings are of grey, greenish grey, and brown siltstones and claystones, and greenish grey sandstones. Sandstones in the cuttings are most abundant between 6,700 - 7,000 feet. Coal is present in cuttings between 7,150 and 7,400 feet and at 8,000 and 8,110 feet. A fragment of sandstone rich in pink garnet was found in cuttings at 8,250 - 60 feet.

Cores 11 to 19 inclusive were taken within the interval and were of light to medium grey and greenish grey, very fine to medium-grained sandstones, and siltstones. Claystone pellets, and evidence of penecontemporaneous deformation was present in cores Nos. 11 - 14, 16 and 17 in the form of convolutions and micro-faulting. Cross-bedding was observed in cores 11, 13, 14, 16 and 19 but in each case was on a small scale. Slight scouring was observed in core 16 (7,225 - 27 feet). All cores except core 11, show very fine interlaminae of carbonaceous material, and core 13 (6,252 - 54 feet) contains root traces.

The thin-section of core 15 (6,716 - 18 feet) is of a typical argillaceous siltstone of the interval. This is a dark grey chloritic, illitic carbonaceous siltstone containing abundant well preserved plant remains. Many of the silt-sized grains are identifiable as quartz or siliceous (?) volcanic grains. Trace amounts of amber were found.

Arenaceous rocks are almost exclusively volcanic sandstones typical of which is the cuttings thin-section at 6,410 - 20 feet. This is a greyish-green, moderately sorted angular to subrounded, fine to medium-grained volcanic sandstone. Quartz and feldspar contents are 10% and 15% respectively. Lithic material makes up 60% and is wholly volcanic, except for some phyllitic fragments. Epidote and zircon are the heavy minerals; muscovite and biotite flakes are abundant.

Quartz varies within the interval up to 15%, but is generally 10% or less. Feldspar, twinned and untwinned, varies between 7% and 35% (7,750 - 70 feet cuttings). Lithic grains are the same as those described from the lower interval.

Core analyses performed by the Bureau of Mineral Resources, (Petroleum Technology Section) reveal good porosities for cores 11 and 12, moderate porosities for cores 13 and 15, and generally negligible porosities for the remainder. The only sample to show any permeability was core 12 (6,242-44 feet) for which 2 md. was recorded. (See Appendices 2 and 3).

Chlorite, zeolite and kaolinitic clay cements are present in the interval as well as calcite, and are discussed more fully, together with the palaeontological data on pages 7 - 9.

Interval 6,000 - 3,108 feet

This interval is definable in terms of its relatively high proportion of sandstone lithology, also in terms of cementing media. Considering both criteria, the lower boundary has been placed at 6,000 feet. The upper boundary corresponds to a genetic change in the sediments and is well represented in cuttings and in electric logs.

Grey and greenish-grey sandstones make up about 30% of the thickness, the remainder being green, greenish-grey, grey and light brown siltstones and claystones. Some coal horizons occur.

In cuttings, the best cemented sandstones are found as rock fragments and the friable, less well-cemented varieties occur as loose sand. The loose sand lithology diminishes in amount toward the base of the interval and ceases to occur below 6,000 feet. Coal occurs in cuttings at the top of the interval between 3,108 feet and 3,570 feet and in very small quantities at other levels. Caved material largely from units Dd and Gf occurs in many of the cuttings within the upper part of the interval.

Cores 5 to 10 inclusive, were taken within the interval. All cores contain carbonaceous material, usually as very fine laminae. Cores 6 and 8 (3,802 - 12 feet and 4,796 - 800 feet) exhibit very fine lamination and abundant penecontemporaneous deformation structures (slight convolution, microfolds and faults). Slight cross-bedding was observed in Core 9 (5,299 - 302 feet) Core 10 (5,807 - 9 feet). Root traces are present in core 5 (3,311 - 13 feet) and abundant in core 10 (5,799 - 803 feet).

Argillaceous rocks throughout the interval are abundantly chloritic and illitic. Flakes of mica and carbonaceous matter are distributed throughout, and spores are present in the thin section of core 7 (4,287 - 89 feet). Only sandstones were thin-sectioned from the cuttings generally, since these reveal most detail. The sandstones are volcanic sandstones and some of the finest sandstones are lithic graywackes. Typically the sandstones are greenish-grey in colour, angular to subrounded, poorly sorted and very fine to medium-grained.

Much of the sandstone has been invaded by calcite which has replaced cement, infilled porosity and replaced labile grains, entirely changing the rock. The sandstones described below are those unaffected by calcitization (i.e. those most closely approximating the true sediment). Cuttings thin-section at 4,080 - 90 feet shows a typical volcanic sandstone containing approximately 75% volcanic grains. Quartz and metaquartzite, plus chert constitute approximately 7% and the feldspar, mostly twinned sodic plagioclase, slightly greater than 10%. Some grains are cemented at points of contact by pellicular chlorite (? syngenetic) around the grains.

Lithic grains are chiefly of acidic volcanic rocks, with a very small quantity of metaquartzite grains. Some volcanic rock grains contain abundant haematite, which may be the decomposition products of (?)mafic minerals. Plagioclase laths within such rock grains are calcic andesine or sodic labradorite. Other lithic grains, such as sphene and epidote bearing lithologies (3,160 - 210 feet, and 5,790 - 99 feet respectively) and cryptocrystalline zeolite grains, are relatively rare.

Feldspar is chiefly sodic plagioclase (approximately oligoclase composition) with minor orthoclase and zoned feldspar.

Abundant epidote and hornblende, with zircon, garnet and rare corundum (Core 8, 4,796 - 98 feet) are the heavy minerals present. Biotite, muscovite and chlorite flakes usually accompanied by flakes of carbonaceous material, are constant components.

High porosities, and zero permeabilities, have generally been determined in core analyses (Appendix 3). The exception is Core 7 (4,295 - 97 feet) which possesses an average porosity of 29%, 'V' permeability of 20 md and 'H' permeability of 3 md. Core 5 (3,311 - 13 feet) which has the highest porosity (32%), possesses nil permeability.

Cementing media and diagenetic products are discussed below.

Cementing Media and Products of Diagenesis.

Several cementing media and diagenetic minerals are observed in unit M. Unless otherwise stated, the minerals described below are from samples with the most readily determinable composition.

By reference to the four minerals - chlorite, zeolite, kaolinitic clay, and calcite, it has been found possible to characterise the various intervals of Unit M, in conjunction with sandstone/siltstone ratios and E-log curves.

Chlorite (general usage)

Green chlorite is present in all sections examined, from units P and M; brown chlorite also occurs in cuttings from 3220-40 feet, 9700-10 feet, and 10220-30 feet.

Chlorite occurs as

(i) a cement, either syngenetic, or diagenetic replacing primary matrix;

and (ii) a constituent of lithic grains.

Interstitial chlorite is common in the fine grained sandstones. In the uppermost interval (6,000-3,108 feet), chlorite occurs as a pellicular cement and also as an apparent replacement mineral of a primary matrix. Sandstones containing pellicular cement are very friable and commonly occur as loose sands in cuttings. These loose sands become less abundant toward the base of the interval and cease to occur below 6,000 feet. A similar, but more indurated lithology, occur at widely spaced intervals below 6,000 feet.

The pellicular chlorite in these sandstones invariably shows "chevaux de frises" form (cuttings thin sections from 3160-210 feet, 6260-70 feet, 10,040-50 feet.)

Chlorite is also abundant as a constituent of the lithic grains; volcanic rock-types are often extensively chloritised. This feature of the lithic grains is one found throughout the unit.

The origin of the interstitial chlorite is not clear but it is evident that, in some cases at least, it is depositional, and it is concluded that the depositional medium was rich in iron magnesium and aluminium ions.

Zeolite

Zeolite also occurs throughout unit P but is largely confined to the horizons below 6,000 feet. Between 6,000 feet and 3,108 the zeolite occurs sporadically and is relatively rare. There appear to be two general forms of occurrence:

(a) Between 6,000 and 3,108 feet zeolite occurs as small euhedra growing inwards from the sides of chlorite-lined pore spaces, (sometimes calcite-lined). Examples occur in thin-section from 3390-410 feet, 3480-520 feet, and 4080-90 feet. In thin-section, this mineral resembles the zeolite found in core 7 (2928-40 feet.) of unit M in Pretty Hill No. 1.

(b) Between 10,308 feet (T.D.) and 6,000 feet, zeolite is present as a diagenetic cement. The relation of the cement to the clastic grains is 'ophitic' (see footnote page 3), the primary cement or matrix having been replaced to produce a continuous zeolite cement.

In such cases, the grains are generally also chlorite-coated. Examples are to be seen in cutting thin-sections from 6290-300 feet, and 9620-40 feet.

In some fine and v. fine-grained sandstones zeolite replaces lithic and feldspathic grains as well as the interstitial material and produces a fine, homogeneous texture. Such a texture is exemplified in cuttings thin-section at 7930-40 feet, in which the grain boundaries are blurred, and difficult to recognise.

In argillaceous rocks there is no definite evidence for the occurrence of zeolite but the texture of some samples in thin-section suggests its possible presence (core 25, 10302-05 feet). Zeolite also occurs in argillaceous rocks as grains which are pale-pink in colour and relatively rare. The zeolite appears to be cryptocrystalline. Other than the latter variety, all the zeolite identified in unit M is a uniaxial negative variety; it is colourless has very low firefringence and shows distinct cleavage in one direction.

Kaolinitic Clay

Kaolinitic clay appears at approximately the same horizon as the abundant zeolite, approximately 6,000 feet, and its last occurrence is at 9,400 feet. Good examples of this mineral exist in cuttings thin-sections from 7930-40 feet, and 7750-60 feet. In mode of occurrence, the mineral resembles kaolinite, and occurs as a mosaic-like mass, replacing feldspars and labile lithic grains as well as the interstitial material. Its birefringence is higher than that of pure kaolinite however.

The crystalline size of the mineral appears to be a maximum near 7700-8000 feet, judging from thin-section examinations.

Calcite

Calcite is clearly the latest mineral to form and all other cements and alteration products are replaced by it; in many cases calcite forms up to 60% of the total rock. The process of calcitization is seen in many stages of development in the thin-sections. Partial calcitization can be seen in a cuttings thin-section at 7150-60 feet. Labile grains are in many cases completely assimilated by the calcite such that the remaining clastic material, the chemically resistant residue, is almost entirely siliceous. Microfaunal evidence indicated that unit M is essentially "non-marine" and this fact together with much petrographic evidence tends to deny the possibility that the calcite is primary in origin.

Available evidence points to the conclusion that the calcite has been introduced at a late stage of diagenesis.

Leucoxene is present throughout as an alteration product of the iron-rich grains. Iron-pyrite occurs generally associated with calcite, in the upper part of the upper interval of unit M.

It is clear that there is a relationship between depth of burial and the degree and the nature of cementation, both from petrographic work and from the effective porosity figures.

In Fig. 1., the divergence of the porosity values from the "normal" shale, porosity/depth curve (Gussow, 1955) is clearly shown. The abundance of diagenetic cementing material is responsible for the intersection of the two trends between 6000 and 7000 feet. This feature is of importance in appraising the petroleum possibilities of unit M.

Stratigraphy.

Microfloral study (Evans, 1963) has shown that above core 8 (4796-814 feet) the Albian stage is present, and below core 19 (8143-156 feet), the Aptian is present. Between these cores the forms are of uncertain stratigraphic affinity.

Possible marine or brackish water conditions are indicated to have been the depositional environment of sediments between cores 5 and 10. Evans, (1963) regards the presence of the hystrichosphere Michrystridium sp. and the pterospermopsid Cymatiosphaera sp. between cores 5 and 10 as possible indicators of such an environment. The remainder of the unit may be non-marine.

Unit Gf.

Unit Gf extends from 3108 feet to 2960 feet. Lithologically and in the electric logs, the unit is distinctive. Uniform S.P. and low resistivity characterises the entire interval. The lithology is dark grey, compact and very glauconitic.. Cuttings do not appear until low in the interval and this is probably due to assimilation of the lithology by the drilling mud.

Glauconite pellets constitute up to 50% of the rock in a cuttings thin-section from 3140-50 feet (caved). Abundant carbonaceous material, chlorite flakes and angular quartz and metaquartzitic grains (silt to v.f. sand-sized), are also present. The pellets, which vary up to 0.5 mm. in diameter, and clastic fragments are set in a clayey, hydromicaceous matrix. Various stages of sideritisation are evident.

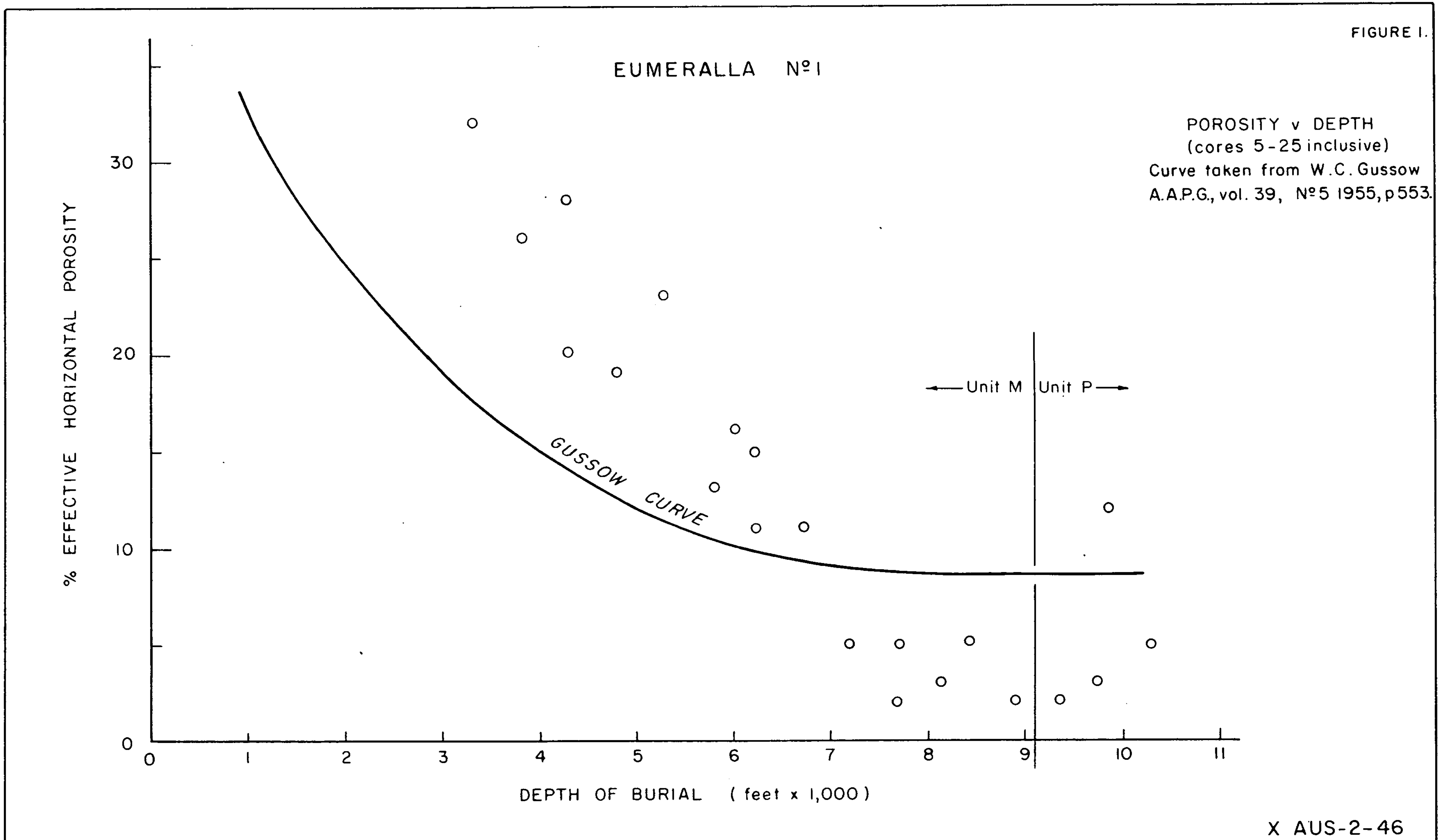
Fragments examined in thin-section exhibit very low porosity and permeability and no hydrocarbons have been detected. The chief interest of this unit probably lies in its ability to act as an impermeable cap-rock.

Absence of planktonic fauna and relative abundance of arenaceous forams has led Taylor (in F. - B.H., 1963 and 1964), to suggest that the depositional environment of the Belfast Mudstones was one of restricted water circulation. This agroos well with the depositional environment of unit Gf envisaged from a consideration of chemical and petrographic features. The depositional medium is considered to have been iron-rich, slightly alkaline and reducing, and of low salinity.

Unit Gd.

The interval is 200 feet in thickness extending from 2960 feet to 2760 feet, the upper limit being marked by a sharp decrease in the S.P. curve toward the shale base-line, and a resistivity minimum. The unit as a whole is characterised by thick intervals of uniform S.P. and resistivity, and some sharp high resistivity maxima. Examples of this are the S.P. curve between 2780 and 2760 feet, the resistivity curve between 2880 and 2850 feet, and the resistivity maximum at 2888feet. Lithologically, the unit is characterised by the presence of sandy carbonate rocks, subarkosic sandstones and pyritic, sideritic siltstones. These rock types are present in cuttings though generally subordinate to caved material. Core 4 was taken from the interval 2849 - 2835 feet.

Between 2839 and 2835 feet, the lithology is greenish-grey compact, angular to rounded (mostly subangular), fine to very coarse-grained, poorly sorted calcareous subarkose (Pettijohn, 1957), containing abundant pellets of (?) glauconite and chlorite. The quartz and metaquartzite makes up between 40% and 50% of the rock. Feldspar (sodic plagioclase and untwinned feldspar) makes up approximately 5%. Pellets of (?) glauconite and chlorite constitute up to 10%, and in hand samples bedding is defined by the variation in concentration of the pellets. Calcite, the cementing medium, appears to have replaced some of the pellets.



Bureau of Mineral Resources Geology and Geophysics April 1965 To accompany record Nº 1965/76

The cement itself is replaced by rhombohedral or spheroidal siderite which grows outward from grain surfaces and in the thin-section of a sample from 2839-41 feet, completely replaces the calcite. In this sample many of the detrital grains are chlorite-coated. Samples from which thin-sections were taken correspond to a resistivity maximum and the samples corresponding most closely to the maximum are those from the lower part of the core. These are friable, dark greenish brown, angular to subangular, very fine to medium-grained, moderately sorted subarkoses. Abundant (?) glauconite and chlorite pellets, and muscovite flakes are present and the matrix is argillaceous. Trace quantities of coal grains, detrital collophane, glaucophane, apatite and garnet are also present.

Judging from the microlog, the latter lithology is predominant between 2940 feet and 2820 feet with interbedded carbonate-cemented horizons.

An Upper Cretaceous age for core 4 (2835-37 feet) is put forward by Douglas (Appendix 2 in Fain, 1963), on the basis of Deflandrea cretacea being present. From evidence obtained from side-wall cores, Taylor (1962) states that the derived arenaceous foraminifera are of Cretaceous age.

In spite of high compositional maturity, sorting is generally poor and grains angular or subangular. Salinity appears to have fluctuated between brackish water and freshwater conditions and this is reflected in the incidence of carbonate-cemented horizons. Marine influence is therefore thought to have been slight and sporadic; unit Gd is considered to mark the end of a transgression and the beginning of a regression.

The petroleum possibilities are confined to consideration of reservoir characteristics. Most of the unit Gd sediments appear to have moderate to good porosity and permeability. Core analysis of the core sample from 2841 - 39 feet reveals that it has porosity of 18% (H) and permeability of 100 md. There is little difference in the thickness of this unit between Pretty Hill No. 1 and Eumeralla No. 1 wells.

Unit Gb.

The unit is relatively thinly developed and extends from 2760 feet to 2660 feet. Comparison of the equivalent log interval of the Pretty Hill No. 1 well enables the boundaries to be placed. The electrical characteristics of the unit shows little similarity to unit Gb of Pretty Hill, and the presence of the unit is postulated chiefly on the evidence of its recognisable limits; at 2660 feet, the base of unit Dd, and at 2760 feet the top of unit Gd.

Cuttings were badly contaminated with caved material, particularly from unit Db, and from unit Dd, and very little evidence of the lithology, as shown in Pretty Hill No. 1, was found. The cuttings lithology was angular to subrounded, fine to v. coarse-grained, moderately sorted loose quartz sand. A notable proportion (between 10% and 30%) of the grains show extreme angularity, though no grain-surface frosting was detected. Two sharp resistivity maxima occur in unit Gb in Pretty Hill No. 1

well but only one is definitely identified in Eumeralla No. 1 well. This peak is thought to coincide with a very thin coal horizon.

The state of the cuttings indicates that cementation was poor. No definite sign of cement was found in cuttings but the electric logs indicate that clay material was present reducing porosity to a variable extent.

The unit consists, most probably, of poorly consolidated, angular, coarse-grained quartzose sandstones and argillaceous beds, with lithological gradations between the two. Reservoir properties are probably of a low order.

Unit Dd.

Extending from 2660 feet to 2530 feet, the unit is of closely similar thickness to unit Dd of the Pretty Hill No. 1 well. Comparison of the resistivity, S.P. and microcaliper logs with those of the above well reveals good correlation.

Cuttings contain large quantities of caved material from unit Db, and the true lithology is in many cases subordinate. No cores were taken in the interval.

The chief lithologies are sandy siderite, siderite-cemented limonite oolites (sandy in some cases and a few samples bear calcite), and siderite rock with (?) glauconite and chlorite pellets. Thin-section examination of the above lithologies shows that the sand fraction is almost exclusively of quartz or meta-quartzite (with rare untwinned feldspar). Grains are angular, very fine to very coarse-grained and generally poorly sorted. Ooliths and pellets present a varied aspect.

The nuclei of many ooliths are angular quartz grains, some of which show corrosion by the coating. The remainder have a green or brown chloritic pellet as nucleus or a limonite pellet. Coatings are all of limonite (cuttings thin-section from between 2610-60 feet) and concentric lamination is preserved. It is clear that recrystallisation or replacement of the coating has taken place and no evidence of initial composition was discovered, such as a partially replaced coating. A second stage of replacement has occurred in parts, involving the coatings and the siderite cement; the outermost layers of the coating and in some cases the whole coating, have been replaced by siderite. Pellets are either of chlorite (brown and/or green) or limonite. These also show a good deal of replacement by siderite cement.

Siderite appears to be the dominant cementing medium in cuttings with subordinate calcite in some fragments. Chlorite cement is present in small quantity in the cuttings thin-section from 2610-60 feet which also contains small patches of siderite in an early stage of development.

All these cementing media were present in the Pretty Hill No. 1 well (Edworthy 1964) but the alteration appears to be more advanced in Eumeralla No. 1.

Unit Dd is considered to lie unconformably on unit Gb. The nature of the unconformity is not apparent, because there is probably little, if any angular discordance. These deposits are thought to follow the culmination of a phase of regression. Very little terrigenous material was supplied to the iron-rich, high-energy environment of deposition and the deposition was mainly chemical in nature, in this part of the basin.

The age of unit Dd is tentatively considered as of Palaeocene age.

The petroleum possibilities of this unit are slight; rocks observed in thin-section and with binocular microscope are hard, chemically cemented lithologies with very low porosity.

Unit Db.

The unit which extends from 2530 feet to 1270 feet is of relatively uniform lithology and contains numerous thin silty intervals. Carbonate-cemented horizons occur near the base of the unit (Between 2300-2400 feet), and thin coal seams occur near the top of the unit (above 1700 feet). The uniformity of the sequence is best shown in the electric logs; the microcaliper log shows some irregularity between 1890-2000 feet where a thick mud cake is formed. One core was taken between 2121-2109 feet (Core 3), but was completely disaggregated, and no trace of the cementing medium was found. Caved material from above 1270 feet is abundant.

Grey, friable, poorly cemented, angular to subrounded (mostly subrounded), fine-grained to granule sized, moderately sorted quartz sandstone is the dominant lithology. Grains are characteristically well polished. Pyrite and muscovite are abundant, and tourmaline and amber are common accessories.

On the basis of the interbedded lithologies, a subdivision of unit Db into two sub-units is possible.

Sub-unit Db_2 (2530 - 2400 feet)

Carbonate-cemented horizons occur at the bottom and top of the sub-unit. These are fine-grained, calcite cemented sandstones and sandy siderite rock horizons; the sideritic lithology appears to be most abundant (cuttings thin-sections, 2410-60 feet, 2420-2500 feet). The sand fraction of the rocks are angular quartz and metaquartzite grains, and rare feldspar. Pyrite is common.

Dark, micaceous siltstone occurs between 2430-60 feet. The dominant lithology is the poorly cemented quartz sandstone described as characteristic for the unit as a whole.

Sub-Unit Db_1

Interval 2400-1700 feet. The sequence is a monotonous series of poorly cemented quartz sandstones (as described above). A change in the mud-cake thickness, perhaps reflecting increased formation permeability, occurs between approximately 2000-1890 feet, but

the electric logs show no appreciable changes, neither are there any lithological changes observed in the cuttings.
Core 3, taken between 2121 - 2109 feet, was studied and although no cemented portion was found, thin-sections were made of the grains. Quartz, generally stressed, and metaquartzite grains, made up the core, along with rare untwinned feldspar.

Siltstones occur as a very subordinate lithology and these are dark brown, micaceous and pyritic. Thin coal flakes are often found in the siltstones.

Interval 1700 - 1270. The electric logs indicate little or no change in the general lithology; resistivity is high with numerous minima and the upper limit of unit Db, is well marked. No cores were taken from the interval. Up to 90% caved material is present in the cuttings (between 1290 - 1330 feet), mostly marl from unit Bb. Dark, carbonaceous, pyritic, micaceous siltstone forms up to 30% of the cuttings. Coal fragments occur in samples 1320-30 feet, 1450-70 feet, 1630-70 feet.

Loose quartz sands dominate the lithology of the interval. These are subangular to rounded, moderately sorted and fine-grained to granule-sized sandstones. As in the lower intervals of the unit, there is no trace of the cementing medium (or matrix), and the sandstone lithology is completely disaggregated in cuttings samples. It would appear that the interstitial material was clay, and was completely removed in drilling. Pyrites and muscovite flakes are abundant, and tourmaline is a common heavy mineral.

No faunas were found in core 3 (2121-109 feet). Taylor (1963) has found Globigerina linaperta in cuttings below 1400 feet and regards this part of the sequence to be Eocene age; he has found the planktonic form, Globorotalia chapmani, characteristic of the Victorian Palaeocene, to be present in cuttings at 2000 feet.

The depositional environment of these deposits is difficult to interpret from cuttings alone. The information available suggests that it was of the paralic type, perhaps deltaic.

No probable source rocks were found in unit Db. The reservoir characteristics are not known but it is likely that they are not good, if the postulated argillaceous matrix is present.

Unit Bc.

The top of the unit (at approximately 1110 feet), is well marked lithologically but the change in electrical properties is gradational. In the resistivity logs, the base of the unit is well marked at 1270 feet and the lithology indicates that the contact between units Bc and Db is unconformable. Within unit Bc, the S.P. curve has a more negative value than that possessed by unit Bb rocks.

Incursion of arenaceous sediments is evident from the cuttings and a thin section of cuttings between 1100 - 1150 feet has been taken as well as one of core 2 (1160 - 72 feet). Examples of the lithology are given below. A marly, dolomitic, angular to subangular, moderately sorted, fine to medium-grained sandstone occurs at the top of the unit, and it contains pellets of glauconite.

As in the remainder of the unit, the clastic grains are mainly of quartz with rare feldspar (untwinned, or microcline). Grains from cuttings throughout the interval and those studied in thin-section of core 2 are limonite coated. Foraminifera, gastropod and pelecypod fragments, as well as organic matter is present in the core. The cement is rhombohedral siderite. Grains up to granule-size are present in cuttings from the base of the interval, and these are generally well rounded.
The general lithology of unit Bc is typical of the "Nelson formation" as found elsewhere.

The base of unit Bc is tentatively considered as the base of the Oligocene. Turbulent, shallow marine brackish water conditions are envisaged as the depositional environment for these sediments. Supply of terrigenous material and chemical precipitation are of the same order of magnitude. The porosity of core 2 is high and there is moderate permeability.

Unit Bb.

Interval 1110-980 feet Numerous resistivity peaks occur over this interval and appear to correspond to thin limestone horizons in marl. Rare limonite pellets are present in the limestone. The marl lithology is buff-coloured and richly fossiliferous, and at the base of the interval becomes slightly sandy. No cores were taken and cuttings contain abundant caved material. Gastropoda, foraminifera, polyzoa and echinoid fragments are abundant.

Interval 980 - 550 feet This is a succession of soft, grey, fossiliferous, slightly glauconitic marls. In cuttings, the argillaceous materials has been mostly removed and the abundant faunal remains are concentrated.

No marl lithology is recovered from the cuttings until 50 feet below its upper boundary, and caved material from above persists throughout.

Upper and lower limits of the interval are well marked in the electric logs.

The fauna is rich and varied, because of the caving, but an interesting point is the incidence of gastropod remains with the incidence of argillaceous material. (i.e. gastropods are confined to this interval). Gastropods are also noticeably more abundant in the lower part of the interval.
Core 1 (941-956 feet) was taken within the interval.

Interval 550-10 feet. The resistivity curve shows numerous high maxima and the overall resistivity is high. Several marly horizons occur in the lower half of the interval but the dominant lithology is light grey porous biocalcarenite, made up chiefly of polyzoa and (?)scaphopod debris. The buff colour of the topmost 70 feet of cuttings is probably due to weathering.

Unit Bb sediments are open-shelf marine deposits.

A gradual decrease in the amount of terrigenous material and increase in the amount of carbonate is clearly evident from the base of unit Bc to the topmost horizons of unit Bb, probably a function of distance from the shore-line.

Conclusion

The greenish grey volcanic sandstones, siltstones and claystones of unit M show remarkable uniformity of lithology from approximately 9110 feet to the top (3108 feet). Some features characteristic of the unit 'R' lithology of Pretty Hill No. 1 well are recognisable in certain strata below 9110 feet in unit P. Units J and Gh (Waarre Fm. and 'Flaxman's Beds' respectively) of other parts of the Otway Basin, are not present. The Upper Cretaceous units (Gf, Gd and Gb) are lithologically well characterised. Unit Dd is overlain by 1260 feet of fine-grained to granule-sized orthoquartzitic sandstone (unit Db). The limonitic carbonate-cemented sandstones and marls of unit Bc and the limestones and marls of unit Bb make up approximately 1270 feet.

Several horizons in unit P contain abundant metaquartzite grains at the expense of the acidic to intermediate volcanic rock fragments which are so abundant in typical unit M Volcanic sandstones. These same horizons contain conspicuous garnet and microcline, and are of medium to coarse-grained, and poorly sorted sandstones which are probably the lithofacies equivalent of unit R of Pretty Hill No. 1

Material from a regionally metamorphosed source area and from an acid to intermediate volcanic source area were carried into the basin during unit P times. Slight and fluctuating supply from the metamorphic source virtually ceased after unit P times. Upper Cretaceous and Tertiary sediments show greater maturity than those of units P and M.

Unit M shows no important change in composition of the clastic material. The abundant lithic material, volcanic in part, is confined to the Lower Cretaceous sediments (Units M and P). Twinned sodic plagioclase ($Ab_7 An_3 - Ab_9 An_1$) is also confined to units M and P. Hornblende is a conspicuous heavy mineral between 6000 feet and the top of unit M.

In the Lower Cretaceous sediments, subdivision has been performed on the basis of differences of cementing media chlorite, kaolinitic clay and zeolite. Authigenic sphene occurs in some unit P sediments. Calcite occurs at numerous horizons, and may replace other cementing media.

Non-marine conditions of deposition appear to have changed in upper unit M times from non-marine to marine. The supply of terrigenous material fell abruptly at the beginning of unit Gf times and quiet, (?) shallow brackish water conditions gave way to slightly more saline conditions in lower unit Gd times. A regression followed which reached its limit before unit Dd times and unit Dd is believed to rest unconformably on unit Gb with possible angularity. Carbonate rocks in lowest unit Db times indicate brief renewal of marine conditions, but the remainder of the sediments are of a paralic aspect and thin coal seams are present at the top of the unit. Limonitic sandstones and carbonate rocks of unit Bc unconformably overly unit Db and true marine conditions become established.

Fluorescence of cuttings and cores (see App. 2) was reported at several horizons within units P and M. Drill stem tests Nos. 1 and 2 show that these horizons are impermeable.

. Gas was detected at numerous horizons chiefly below 3300 feet, but there was a small mud-gas detector deflection between 2130-60 feet. These gas occurrences were all related to coal horizons.

Though porosity was generally high to very high in units P and M, permeability was determined as nil for all cores except Nos. 7, 12 and 24 (see App. I and II), and cuttings examination revealed no horizons with good reservoir characteristics. Unit Gd and Bc possess horizons of more promising reservoir characteristics, having good porosity and moderate permeability.

Palaeontological evidence below unit Gf is sparse. Evidence suggests that core 20 of Pretty Hill No. 1 Well is possibly of Jurassic age and is as old or older than the base of the Eumeralla section. Douglas (1963) regards the interval between cores 4 and 5 (2849-3311 feet) to be non-marine, pre-Upper Cretaceous in part. The lower boundary of the Upper Cretaceous has been placed at 3108 feet corresponding to the top of unit M. Unit Dd has been considered as of Palaeocene age although the Palaeocene appears to extend up to 2000 feet at least (Taylor, 1963).

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Appendix 1

Cuttings Description

10 - 80 feet.	Medium buff coloured (10YR 7/6)* biocalcarenite; abundant foraminifera, polyozoa and (?) scaphopoda.
80' - 600 feet.	Grey (5Y6-5/2) friable, porous, slightly glauconitic biocalcarenite with minor caved, buff biocalcarenite.
600 - 1020 feet.	Light olive to yellowish grey (5Y 6/1 to 5Y 8/1) fossiliferous, glauconitic marl, with subordinate biocalcarenite dying out towards the base of the interval.
1020 - 1110 feet.	Grey fossiliferous, glauconitic marl and grey biocalcarenite.
1110 - 1140 feet.	Well sorted, angular, v. fine to medium grained loose quartz sand, and fossiliferous, glauconitic marl. Lt. brown, carbonate-cemented quartz sandstone and grey fossiliferous. Limestone occur at the base of interval, (1130-40 feet)
1140 - 50 feet.	Lt. grey fossiliferous limestone
1150 - 1200 feet.	Lt. brown, well-sorted carbonate cemented sandstone and minor lt.-grey fossiliferous limestone.
1200 - 1320 feet.	Grey fossiliferous marl and loose quartz sand, some iron-stained, containing limonite pellets.
1320 - 1450 feet.	Subangular to subrounded, moderately sorted, coarse grained to granule-sized loose quartz sand, and fossiliferous marl (caved). Sand contains abundant muscovite flakes, and pyrite. Dark micaceous carbonaceous siltstone makes up 25% of samples.
1450 - 70 feet.	As above, except that siltstone contains coaly lenticles.
1470 - 1630 feet	As 1320 - 1450 feet, with siltstone forming up to 30%
1630 - 70 feet	As 1320 - 1450, except siltstone contains coaly lenticles.
1670 - 1870 feet	As 1320 - 1450 feet.
1870 - 2420 feet	Subangular to subrounded, moderately sorted, fine to granule-sized loose quartz sand. Pink and grey (?) chert or metaquartzite grains, pyrite and abundant muscovite flakes. Dark brown carbonaceous, micaceous siltstone and fossiliferous marl occur in small amount at intervals.
2420 - 2560 feet	As 1870-2420 feet; incidence of moderately sorted, fine-grained sandstone with sideritic cement (5%)

* Geol. Soc. Amer. 1963 (Munsell colour chart.)

2560 - 2660 feet.	Sandstone with abundant limonite pellets and limonite coated quartz grains, cemented by siderite. Slightly pyritic. Loose quartz sand, as 2420-2560, containing limonite pellets and abundant pyrite.
2660 - 2710 feet	Silty, siderite- cemented sandstone containing limonite ooliths and pellets, loose quartz sand (containing an increased amount of fine material). First occurrence of lt.-brown, fine to medium - grained calcite comented sandstone
2710 - 2850 feet (No samples 2835-50 feet)	As 2420-2560, but no caved marl. Sideritic lithology becomes silty toward the base of the interval.
2850 - 2890 feet	Dark brown pyritic, (?)glauconitic siltstone, angular to subrounded, coarse-grained loose quartz sand (containing abundant pyrite) and minor siderite cemented sandstone.
2890 - 3020 feet	Carbonate cemented sandstones, silty in part. Siderite dominant as cementing medium. Angular to subrounded, coarse-grained loose quartz sand constitutes the remainder of the samples, apart from minor caved marl.
3020 - 50 feet.	Angular to subrounded fine-grained loose quartz sand, with coarse, caved grains. Minor caved marl.
3050 - 70 feet	As 2890 - 3020 feet, except for different grain size of loose sand.
3070 - 3170 feet	Loose quartz sand (as 3020 - 50 feet) and dark, V. glauconitic pyritic siltstone. Glauconite pellets constitute up to 30% of the samples.
3170 - 80 feet	As above (3070 - 3170 feet), but containing in addition, 10% calcite cemented lithic sandstone and approximately the same quantity of pale green claystone, with plant remains.
3180 - 3330 feet. (No sample, 3310-20 feet.)	Angular to subrounded, fine to medium grained loose quartz sand and pale green or grey claystonesand siltstones. Minor dark grey '. glauconitic siltstone.
3330 - 70 feet	As 3180 - 3330 ft. with up to 15% siderite and and sandy siderite rock
3370 - 90 feet	As 3180 - 3330 feet.
3390 - 3820 feet	As 3180 - 3330 feet with up to 40% calcite-cemented sandstone, abundant in the upper part of the interval. Coaly fragments are common down to 3570 feet. Below this horizon the lithology is dominantly subangular, moderately to well sorted, fine-grained, loose sand containing abundant lithic grains.
3820 - 3910 feet	Grey, pale green, pale brown and dark brown siltstones and claystones containing abundant flakes of carbonaceous material.

3910 - 4200 feet	Siltstones and claystones as above (3820 - 3910 feet) and moderately to well sorted, angular to subangular medium-grained loose lithic sand.
4200 - 4490 feet (No sample 4300 -40)	As 3910 - 4200 feet, with loose lithic sand and calcite-cemented sandstone; coal fragment at about 4400 feet.
4490 - 4700 feet	Claystones and siltstones (as 3820 - 3910 feet) and moderately to well sorted, very fine to fine-grained, calcite and chlorite cemented sandstone.
4700 - 4810 feet (No sample 4796-810 feet)	As 4200 - 4490 feet.
4810 - 5160 feet.	Mostly grey siltstones and claystones (some greyish brown or green), and calcite or chlorite-cemented sandstones. 20% coal in the cuttings at 4820-30 feet.
5160 - 5980 feet.	Claystones and siltstones grey or greyish, green, and chlorite and/or calcite cemented sandstones. Loose sands are either of dominantly lithic composition of quartzose composition or composed of both types. The lithic type is abundant above 5400 feet. Tbe quartzose type is caved (from Unit Db) and occurs mainly at 5460 -70 feet, 5530-40 feet, 5600-10 feet. Coal occurs at 5830-40 feet and at 5920-30 feet.
5980 - 6510 feet.	Dark and light grey brown, greyish-brown and and greenish grey claystones and siltstones, containing abundant carbonaceous material, and zeolite and/or chlorite cemented lithic sandstones. Caved quartz sand occurs at 6480 - 90 feet, and 6500 - 10 feet. Coal occurs at 6010 - 30 feet, and 6130 - 40 feet.
6510 - 9130 feet.	Siltstones, claystones and sandstones, as above, in varying proportions. Other than in nature and degree of cementation, no compositional change is apparent. Cementation is discussed in the text. Coal fragments occur at numerous horizons between 7150-7390 feet, and is also present between 8000-10feet, and 8100 10 feet. Below 8510 feet coal is relatively abundant in the cuttings, especially between 8750-60 feet. Caved loose sand occurs at several horizons, the most important being at 6860 -6900 feet and 7520-60 feet; these are clearly derived from unit Db.
9130 - 10.300 feet.	Dark and light grey, greenish grey and brownish grey siltstones and claystones show little variation from those already described (ie 5980 - 6510 feet). Sandstones occur throughout and are generally well cemented. Most of the sandstones are closely similar to those already described, but nearly all show some slight differences. These may be either one of the following features. (i) abundant garnet, (ii) very poor sorting, (iii) above average to grain size. (relative to sandstones of unit M. (iv) lighter colouration (due to the lower proportion of dark lithic fragments)

(i) abundant garnet,
(ii) very poor sorting,
(iii) above average grain size; (relative to sandstones of unit M.)
(iv) lighter colouration (due to the lower proportion of dark lithic fragments)

The features are well represented by sandstones in cuttings samples between 9130-200 feet, 9870-10300 feet. Smaller quantities of this sandstone lithology are present between 9200-9870 feet.

Traces of coaly matter are frequent and more appreciable amounts (10-20%) occur above 9250 feet, between 9350-70 feet, and 9640-50 feet.

APPENDIX II

CORE ANALYSIS SAMPLE DESCRIPTIONS

Core 1 (941-961 feet)	Too friable to analyse.
Core 2 (1162-1164 feet)	Soft, medium brownish grey (5YR 4/1)* angular very fine to medium-grained, poorly sorted argillaceous sandstone. The quartz grains are limonite coated, and the largest grains are well rounded. Limonite, calcareous matter, and pyrite are abundant in the matrix. Pelecypod and foraminifera remains are also abundant. Porosity is very high and permeability is moderate; 31-32% and 84-100 mD respectively.
Core 3	Unable to analyse.
Core 4 (2839-41 feet)	Light olive grey (5YR 6/2) well-cemented, angular to subrounded, very fine to medium-grained, moderately sorted orthoquartzitic sandstone. Abundant (?) glauconite and chlorite pellets. The porosity if partly filled by primary siderite and the residual effective porosity is 18% (H). Relatively low porosity and high grain density have produced a high bulk density. The siderite cement is the cause of the high grain density. Permeability is moderate.
Core 5 (3311-13 feet)	Grey (5YR 5/1) silty claystone containing carbonised plant remains. Bedding not visible. Abundant coaly grains and muscovite flakes. Porosity very high (32%); permeability nil.
Core 6 (3810-12 feet)	Grey 2.5Y 7/0) silty claystone containing abundant small carbonaceous flakes, and abundant micaceous material. Porosity high (26%); permeability nil.
Core 7 (4295-97 feet)	Light grey (5Y 6/1) compact siltstone, containing numerous claystone pellets. Clay matrix. Porosity high (30% - V, 28% - H) and permeability slight (20mD - V, 3mD - H).
Core 8 (4800-04 feet)	Light grey (2.5Y 7/0) compact claystone. Very fine flakes and fragments of carbonaceous matter are distributed throughout the samples which show no bedding.
Core 9 (5299-5302 feet)	Light grey (5Y 6/1) compact angular to subrounded, very fine-grained, moderataly sorted sandstone. No bedding visible. Abundant flakes of carbonaceous material. Biotite, chlorite and muscovite flakes abundant. The matrix is chloritic and argillaceous, and contains trace of calcareous material.

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* Geol. Soc. Amer. 1963 (Munsell Colour Chart)

Core 10 (5809-11 feet)	Light yellowish grey (2.5Y 7/0), compact angular, very fine-grained sandstone, with fine discontinuous carbonaceous laminae. Abundant chlorite, biotite and hydromica. High porosity (21% V, 13% H) and nil permeability.
Core 11 (6046-48½ feet)	Light yellowish grey (2.5Y 6.5/0) siltstone, with finely interlaminations of carbonaceous material. Slight small-scale cross-bedding Good porosity (17% V, 16% H), nil permeability.
Core 12 (6242-44 feet)	Light grey, compact, moderately sorted, angular to subrounded, fine to medium-grained sandstone. Cement chlorite and zeolite; abundant carbonaceous grains. Bedding faint; elongated claystone pellets lie along bedding planes. Moderate porosity (16% V, 15% H) and low permeability (2md).
Core 13 (6252-54 feet)	Light grey (5Y 6/1) interbedded siltstones and argillaceous siltstones. Good root traces present. Bedding thin, and shows signs of slight penecontemporaneous deformation Abundant carbonaceous laminae. The much lower porosity is perhaps due to the presence of cryptocrystalline zeolite, but no definite evidence exists. Permeability nil.
Core 14 (6478-88 feet)	NO RECOVERY.
Core 15 (6712-14 feet)	Light yellowish grey (2.5Y 7.5/0) compact, angular to subrounded moderately sorted, very fine-grained sandstone. Coaly grains are concentrated in thin laminae. Chlorite cement partly infills porosity. Porosity fair (11%) and permeability nil.
Core 16 (7227-29 feet)	Light yellowish grey (2.5Y 6.5/0), compact, angular to subrounded, moderately sorted, very fine-grained sandstone, containing large coal flakes and grains. Calcite cement has replaced chlorite cement and is responsible for the low porosity (8% V; 5% H), and nil permeability. The increase in bulk density corresponds to this decrease in porosity.
Core 17 (7709-12 feet)	Grey (2.5Y 5/0) compact argillaceous siltstone, containing abundant carbonaceous material. Bedding indistinct. Chloritic material and biotite flakes abundant. Porosity low (4% V; 2% H), and permeability nil.
Core 18 (7716-17 feet)	Medium grey (N4), hard, silty claystone; no bedding visible. Numerous root traces. Porosity (5%) and permeability nil.

Core 19 (8147-49 feet)	Light grey (2.5Y 5.5/0) faintly laminated siltstone containing abundant carbonaceous material. Slightly calcareous. Porosity negligible (3%); permeability nil.
Core 20 (8463-65 feet)	Light yellowish grey (2.5Y 7/1) hard, silty very fine-grained sandstone. Abundant carbonaceous grains; very slightly calcareous. Negligible porosity (4% V, 5% H) and permeability nil.
Core 21 (8914-8916 feet)	Light grey (2.5Y 6/0), hard silty very fine-grained sandstone. Carbonaceous flakes and grains abundant; bedding not visible. The cementing medium is distinctly calcareous. Porosity is negligible and permeability nil.
Core 22 (9383-85 feet)	Light grey (2.5Y 6/0), hard slightly sandy siltstone with thinly interbedded carbonaceous siltstones. Small-scale cross-bedding. Very slightly calcareous cementing medium. Porosity negligible (2%) and permeability nil.
Core 23 (9769-72 feet)	Medium grey, (2.5Y 4.5/0) hard, unlaminated argillaceous siltstone. Abundant finely disseminated carbonaceous material. Root traces in growth position present. Porosity negligible (3%), and permeability nil.
Core 24 (9881-90 feet)	Light grey (5Y 7/1), hard, angular to sub-rounded, fine to medium-grained, poorly sorted sandstone. No bedding visible. Pink garnet conspicuous. Zeolite cement has infilled much of the primary porosity. Porosity moderate, (13% V, 12% H) and permeability moderate (2md).
Core 25 (10300-02 feet)	Light grey, (2.5Y 6.5/0), hard silty v. fine -grained sandstone. Bedding indistinct. Poorly-defined interbedded carbonaceous laminae. Zeolite and chlorite cementation infills virtually all porosity and remanent porosity is negligible, (5%); permeability nil.

In the cores taken from units M and P (cores 5 to 25 inclusive), there is a clear relationship between depth and porosity (porosity decreasing with depth); the latter can be related to the increase in the degree of cementation which becomes especially apparent in thin-section, below 6000 feet. Core 24 constitutes a conspicuous exception to this depth - porosity relationship, and this is clearly connected with the exceptional composition of this sandstone. It is the only one of the cores to show well marked mixture of unit R and unit M facies.

APPENDIX III

Petroleum Technology Laboratory, Bureau of Mineral Resources, Geology and Geophysics, Canberra

Date: 6th March, 1963

CORE ANALYSIS RESULTS

Notes (i) Unless otherwise stated, the porosities and permeabilities were determined on two small plugs (V & H) cut at right angles from the core or sample. Ruska field porometer and permeameter were used, with air and dry nitrogen, respectively, as the saturating and flowing media. (ii) Oil and water saturations were determined using Soxhlet type extraction apparatus. (iii) Acid solubilities were determined using 15% commercial hydrochloric acid (iv) N.D. means Not Determined.

Well or Area	Core or sample number	Depth in ft. From: To:	Effective porosity % by Vol.		Absolute permeability millidarcys.		Avg. density in gms/cc.		Fluid saturation			Acid solubility % by vol.	Oil Characteristics		
			V.	H.	V.	H.	Dry Bulk	Grain	Water: % pore space	Oil: % pore space	Oil: Metric tons/acre ft		Fluorescence in solvent	Colour of extracted oil	Fluorescence of extracted oil.
EUMERALLA NO. 1	1	941 961	Very Friable, could not analyse												
"	2	1162 1164	32	31	100	84	1.89	2.75	45	Nil	Nil	N.D.	Trace	Nil oil	Nil oil
"	3	2110 2112	Sample Received in Powdered Form									-	-	-	-
"	4	2839 2841	N.D.	18	N.D	100	2.34	2.86	63	Nil	Nil	N.D.	Trace	Nil oil	Nil oil
"	5	3311 3313	32	32	Nil	Nil	1.94	2.70	40	"	"	"	Faint Trace	"	"
"	6	3810 3812	26	26	Nil	Nil	1.94	2.61	46	"	"	"	Strong	"	"
"	7	4295 4297	30	28	20	3	2.04	2.87	22	"	"	"	Trace	"	"
"	8	4800 4804	19	19	Nil	Nil	2.18	2.68	50	"	"	"	Strong	"	"

Additional information:

General file no. 62/399

Well file no. 62/1308

Petroleum Technology Laboratory, Bureau of Mineral Resources, Geology and Geophysics, Canberra

Date: 6th March, 1963

CORE ANALYSIS RESULTS

Notes (i) Unless otherwise stated, the porosities and permeabilities were determined on two small plugs (V & H) cut at right angles from the core or sample. Ruska field porometer and permeameter were used, with air and dry nitrogen, respectively, as the saturating and flowing media. (ii) Oil and water saturations were determined using Soxhlet type extraction apparatus. (iii) Acid solubilities were determined using 15% commercial hydrochloric acid (iv) N.D. means Not Determined.

Well or Area	Core or sample number	Depth in ft. From: To:	Effective porosity % by Vol.		Absolute permeability millidarcys		Avg. density in gms/cc.		Fluid saturation			Acid solubility % by vol.	Oil Characteristics		
			V.	H.	V.	H.	Dry Bulk	Grain	Water: % pore space	Oil: % pore space	Oil: Metric tons/ acre t.		Fluorescence in solvent	Colour of extracted oil.	Fluorescence of extracted oil.
EUMERALLA No. 1	9	5299 5302	21	23	Nil	Nil	2.05	2.63	22	Nil	Nil	N.D.	Faint Trace	Nil oil	Nil oil
"	10	5809 5811	21	13	Nil	Nil	2.29	2.76	34	"	"	"	Strong	"	"
"	11	6046 6048'6	17	16	Nil	Nil	2.19	2.63	32	"	"	"	Strong	"	"
"	12	6242 6244	16	15	2	2	2.21	2.61	34	"	"	"	Strong	"	"
"	13	6252 6254	10	11	Nil	Nil	2.22	2.54	69	"	"	"	Strong	"	"
"	14		No core available					-	-	-	-	-	-	-	-
"	15	6712 6714	11	11	Nil	Nil	2.34	2.63	61	Nil	Nil	N.D.	Strong	Nil oil	Nil oil
"	16	7227 7229	8	5	Nil	Nil	2.49	2.66	58	"	"	"	Strong	"	"

Additional information:

General file no. 62/399
Well file no. 62/1308

Petroleum Technology Laboratory, Bureau of Mineral Resources, Geology and Geophysics, Canberra

Date: 6th March, 1963

CORE ANALYSIS RESULTS

Notes (i) Unless otherwise stated, the porosities and permeabilities were determined on two small plugs (V & H) cut at right angles from the core or sample. Ruska field porometer and permeameter were used, with air and dry nitrogen, respectively, as the saturating and flowing media. (ii) Oil and water saturations were determined using Soxhlet type extraction apparatus. (iii) Acid solubilities were determined using 15% commercial hydrochloric acid (iv) N.D. means Not Determined.

Well or Area	Core or sample number	Depth in ft. From: To:	Effective porosity % by Vol.		Absolute permeability millidarcys.		Avg. density in gms/cc.		Fluid saturation			Acid solub-ility % by vol.	Oil Characteristics		
			V.	H.	V.	H.	Dry Bulk	Grain	Water: % pore space	Oil: % pore space	Oil: Metric tons/ acre ft.		Fluorescence in solvent	Colour of extracted oil.	Fluorescence of extracted oil.
EUMERALLA NO. 1	17	7709 7712	4	2	Nil	Nil	2.48	2.55	100	Nil	Nil	N.D.	Strong	Nil oil	Nil oil
"	18	7716 7717	5	5	"	"	2.41	2.55	99	"	"	"	Strong	"	"
"	19	8147 8149	3	3	"	"	2.48	2.55	100	"	"	"	Strong	"	"
"	20	8463 8465	4	5	"	"	2.52	2.64	78	"	"	"	Strong	"	"
"	21	8914 8916	3	2	"	"	2.57	2.63	100	"	"	"	Trace	"	"
"	22	9383 9385	2	2	"	"	2.51	2.55	100	"	"	"	Trace	"	"
"	23	9769 9772	3	3	"	"	2.53	2.61	100	"	"	"	Trace	"	"

Additional information: Core No. 24 was received in a sealed condition. Salinity for extracted water 4740 p.p.m. NaCl.
All cores which gave "strong" fluorescence in solvent contained coal or carbonaceous partings and pieces.

General file No. 62/399

Well file no. 62/1308

Petroleum Technology Laboratory, Bureau of Mineral Resources, Geology and Geophysics, Canberra

Date: 6th March, 1963

CORE ANALYSIS RESULTS

Notes (i) Unless otherwise stated, the porosities and permeabilities were determined on two small plugs (V & H) cut at right angles from the core or sample. Ruska field porometer and permeameter were used, with air and dry nitrogen, respectively, as the saturating and flowing media. (ii) Oil and water saturations were determined using Soxhlet type extraction apparatus. (iii) Acid solubilities were determined using 15% commercial hydrochloric acid (iv) N.D. means Not Determined.

Well or Area	Core or sample number	Depth in ft. From: To:	Effective porosity % by Vol.		Absolute permeability millidarcys.		Avg. density in gms/cc.		Fluid saturation			Acid solubility % by vol.	Oil Characteristics		
			V.	H.	V.	H.	Dry Bulk	Grain	Water: % pore space	Oil: % pore space	Oil: Metric tons/ acre ft		Fluorescence in solvent	Colour of extracted Oil.	Fluorescence of extracted oil.
EUMERALLA No. 1.	24	9881 9890	13	12	2	2	2.37	2.67	49	Not Measurable		N.D.	Good	Not Extracted	Trace Only
"	25	10300 10302	5	5	Nil	Nil	2.52	2.61	20	Nil	Nil	N.D.	Trace	Nil oil	Nil oil

Additional information

General file no. 62/399

Well file no. 62/1308

Plate I, Sheet I.

COMPOSITE WELL LOG

EUMERALLA Nº I

LAT. 38° 12' 43"
LONG. 141° 56' 01"
ELEV. (GROUND) 167 ft. A.S.L.
SCALE. 1 inch = 100 ft.

B.M.R. WELL INDEX Nº 158

Company: FROME-BROKEN HILL Co. PTY. LTD.
Basin: OTWAY
State: VICTORIA

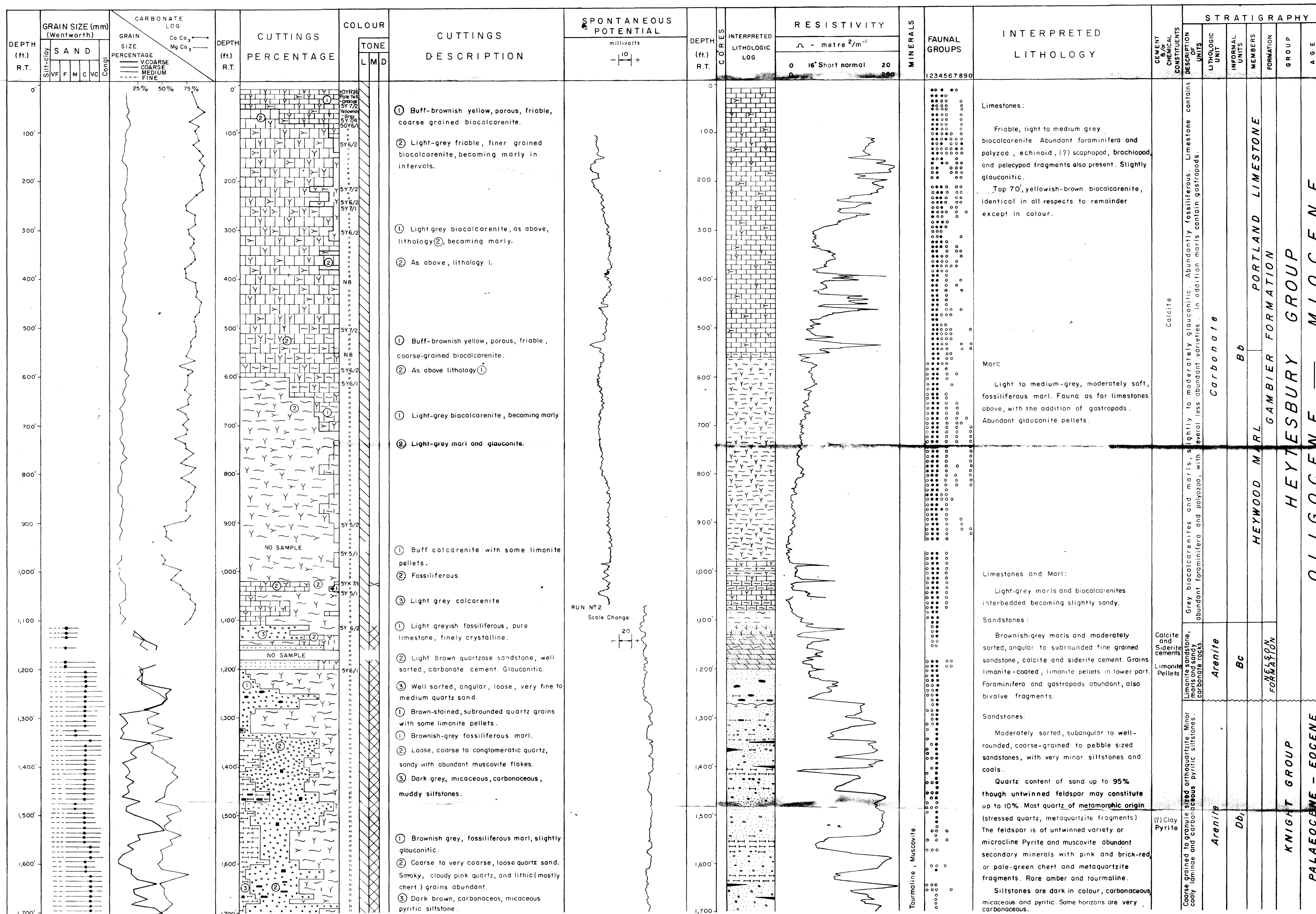
REFERENCE

Sandstone
Siltstone
Claystone
Marl
Dolomite (and sandy dolomite)
Siderite rock (and sandy siderite rock)
Grains > sand-size. (Wentworth)
Coal
Limestone (and sandy limestone)
Y Skeletal debris
Glauconite
Oolith
Pellet
Phosphate
Pyrite
Limonite

FAUNAL GROUPS

1. Gastropoda
2. Foraminifera
3. Polyzoa
4. Scaphopoda
5. Echinoidea
6. Brachiopoda
7. Lamellibranchia
8. Ostracoda
9. Fish fragments
10. Sponge spicules

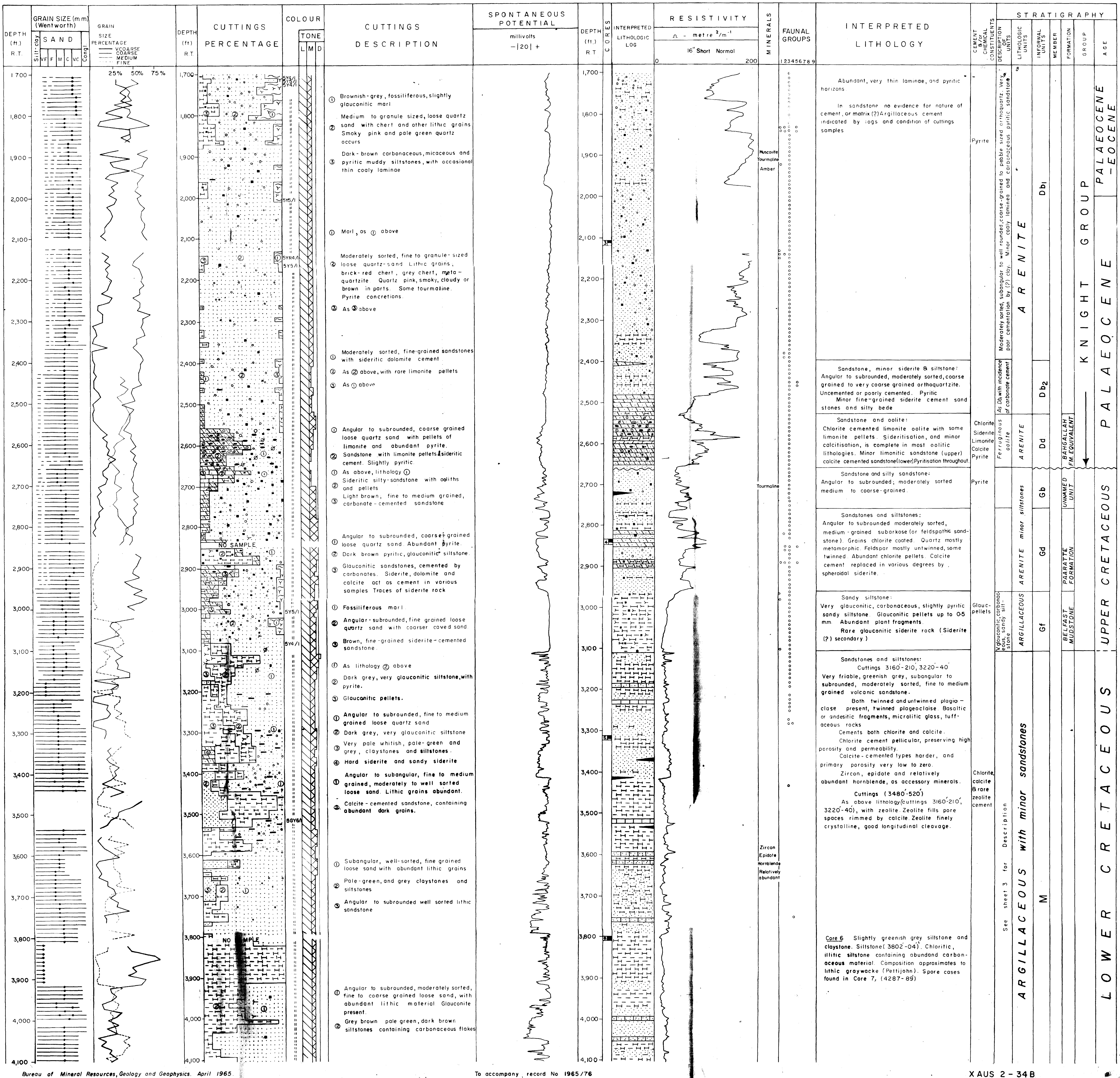
• Abundant
∘ Present



X AUS-2-34A
F.E.

Plate 1, Sheet 2

EUMERALLA No 1

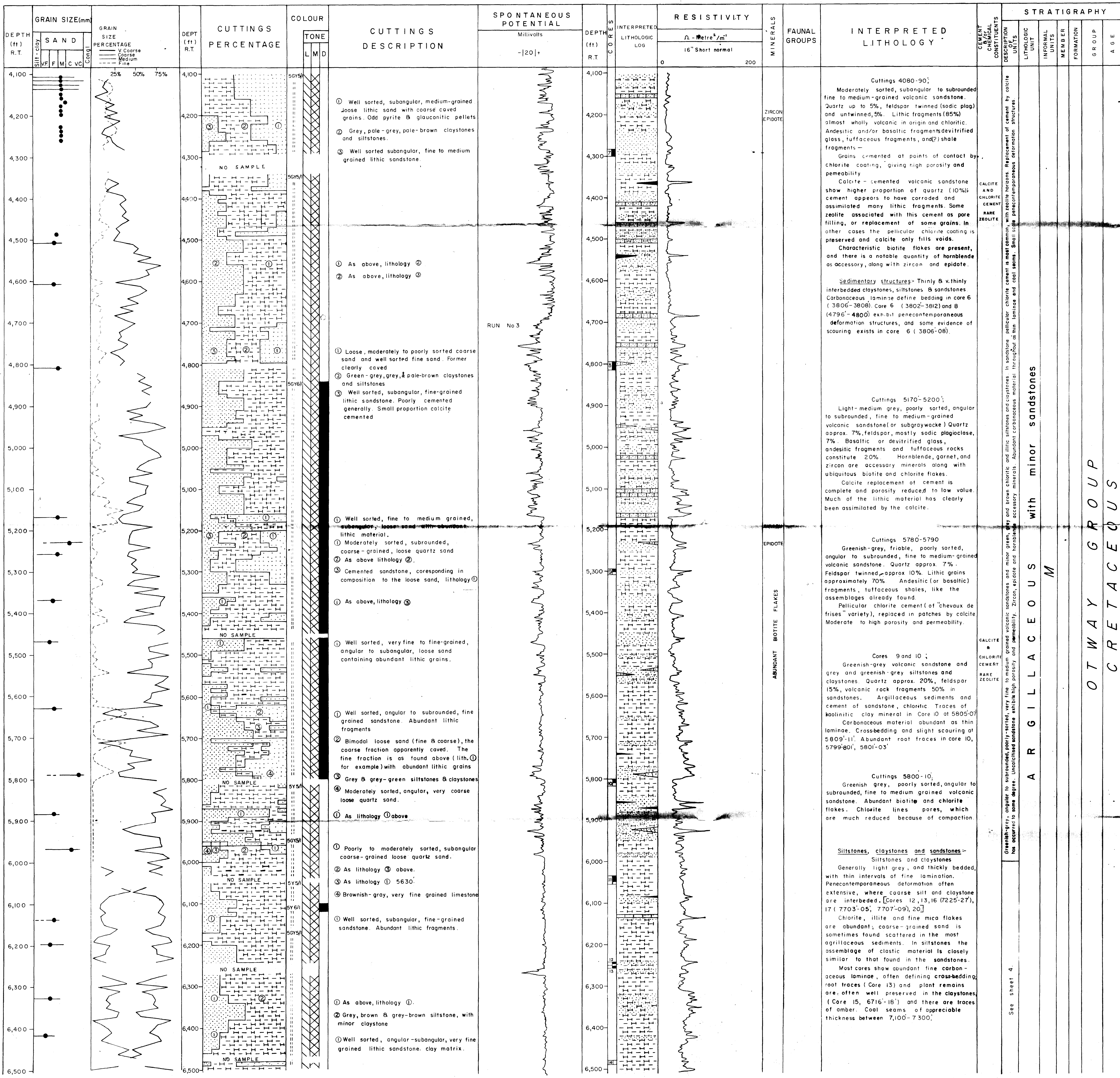


Bureau of Mineral Resources, Geology and Geophysics. April 1965.

To accompany record No 1965/76

X AUS 2 - 34 B

EUMERALLA No 1

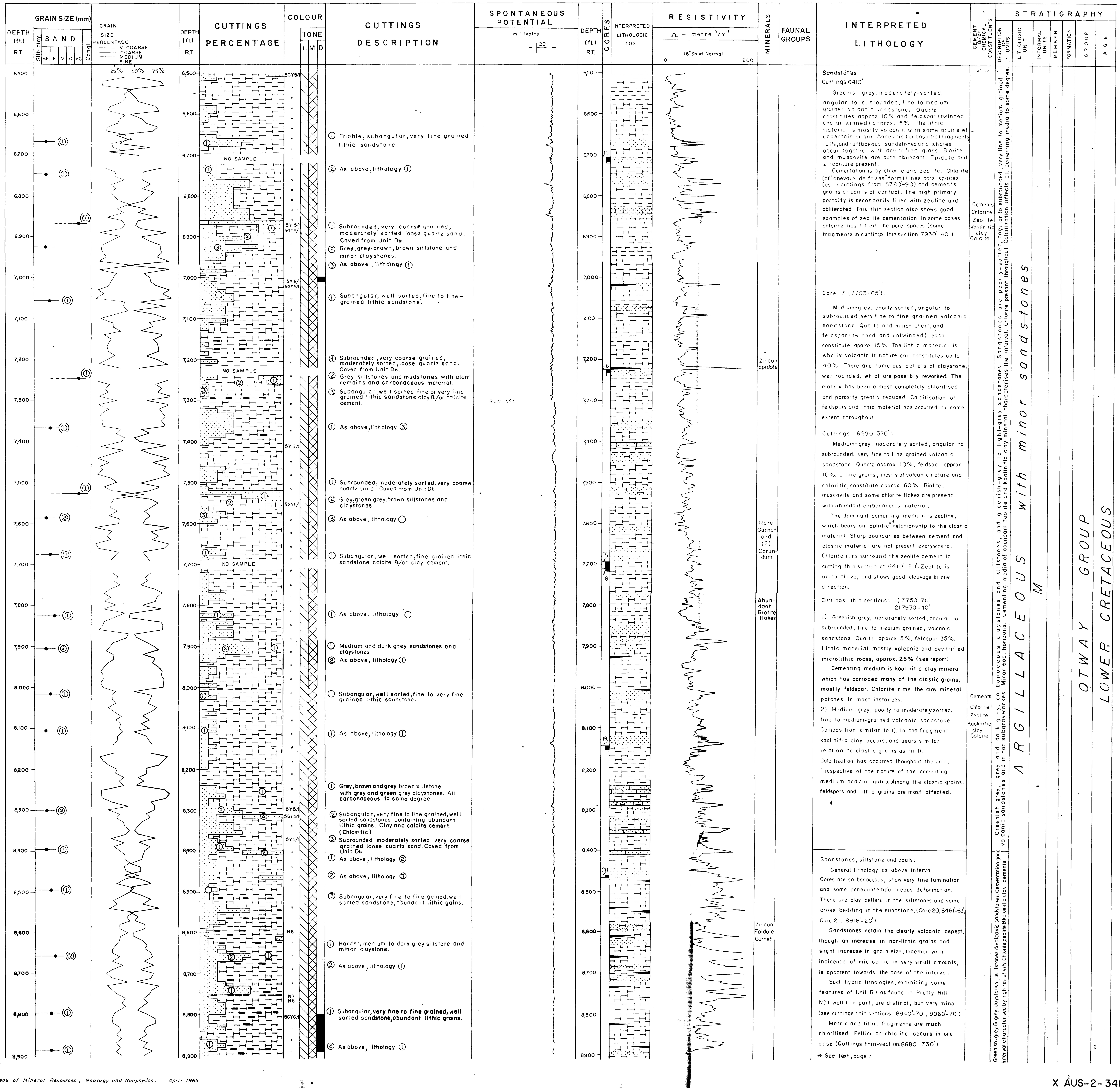


Bureau of Mineral Resources, Geology and Geophysics. February 1965.

To accompany Record No 1965/76

X AUS 2-34C

EUMERALLA Nº I



EUMERALLA No 1