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PETROGRAPHICAL REPORT ON ROCK SAMPLES FROM THE COASTAL SECTION BETWEEN TORQUAY AND AIREY'S INLET VICTORIA.

by

J.E. Glover.

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PETROGRAPHICAL REPORT ON ROCK SAMPLES FROM THE COASTAL SECTION BETWEEN TORQUAY AND AIREY'S INLET. VICTORIA.

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The samples described in this report, which were submitted by the Director for petrographical examination, come from the Janjukian and Anglesean deposits between Torquay and Airey's Inlet. Torquay is 14 miles south east of Geelong.

All sedimentary rocks from the area have been named according to the classification drawn up by M.A. Condon. The results of a rough chemical analysis made in 1947 on a sample of supposed jarosite (W106) are given, and a note on the occurrence and possible origin of the glauconite found in many of the samples, is appended.

The 25 rocks described are labelled as follows:

Bed H FD locality
FD 7 FD locality
Bed J FD locality
Bed K. FD locality
BR 4
Jarosite ? Base Bed BR 4.
BR 5
"H" BR 6
BR 7
Bed J BR 7
Bed K BR 7
Hard Bed 7 BR 12
BR 14
Hard Band (Lst.) in BR 14
Bed "L" at base BR 19
B? (label partly obliterated)
"A" RP/1
"B" in RP/3
Bed "M" Bird Rock
Bed "N" Bird Rock
FB 3 Type Section Torquay
FB 4 Type Section Torquay
A1 (2 specimens)
W 98
W 107

Bed H. FD Locality.

In the hand specimen, the rock is grey, fine grained and non-friable, with black dendritic aggregates of pyrite visible on broken surfaces. The rock effervesces slightly in cold N/10 HCl.

Under the microscope, the rock is seen to consist of a finely crystalline, somewhat turbid mass of carbonate containing angular quartz grains. Carbonate forms possibly 82 per cent of the whole, while quartz grains, which have an average diameter of only 0.04 mm., make up about 9 per cent. Pyrite, as small grains and dendritic aggregates, is often surrounded by an aureole of red-brown iron stains, and accounts for 8 per cent of the rock. The remainder is made up of a few plagioclase grains, patches of brownish material which are difficult to resolve under the microscope but which seem to consist of chlorite and clay, and rare grains of zircon. One carbonate fragment which probably represents a foraminiferal test, is present.

The rock is a silty limestone (calcilutite).

FD 7 FD Locality

In the hand specimen this rock is grey with iron stained patches - it is fine grained, fairly friable and effervesces with cold $\frac{N}{10}$ HCl.

In thin section the rock is seen to be made up of finely granular, even grained carbonate with no obvious organic structure, and an average grain diameter of 0.04 mm. Carbonate forms 95 per cent of the rock, with angular quartz making up 3 per cent. Occasional grains of green glauconitic material, a little pyrite, haematite and leucoxene, and some small, indefinite patches of brownish material, make up the remainder of the rock. Most haematite grains are surrounded by small red-brown areas of stained carbonate.

The rock is a limestone (calcilutite).

Bed J FD Locality

This rock is grey in patches, but is generally red-brown due to oxidation of the iron content. It is fine-grained, slightly friable and effervesces slightly with cold $\frac{N}{10}$ HCl.

Microscopically, this rock consists of an iron-stained mass of finely divided carbonate, probably associated with a certain amount of clay, together with quartz grains and foraminiferal tests. Iron stained material makes up 80 per cent of the rock - in some places the staining becomes concentrated in cores which are entirely opague and are red in reflected light - these cores probably represent haematite. Quartz, as clear, angular grains with an average diameter of 0.04 mm., and a little felspar comprise 19 per cent of the whole.

A few small patches of glauconite, enclosed within foraminiferal tests, can be seen - other minerals present include muscovite, brown biotite, black iron ore and one grain of tourmaline.

This rock is a silty, foraminiferal limestone (calcilutite).

Bed K. FD Locality

This rock consists of a white, friable mass of carbonate, iron-stained in patches, which effervesces with cold $\frac{N}{10}$ HCl.

In thin section, the rock is seen to consist of finely divided, grey carbonate which is red-brown in places due to iron staining, and angular quartz grains. The carbonate may owe its grey colour partly to the presence of argillaceous impurities and makes up 96 per cent of the rock - quartz grains, with an average diameter of 0.04 mm., make up 3 per cent. No recognisable organic remains are present in this section, the only other constituents being felspar, a little chlorite and a few grains of black iron ore.

The rock is a limestone (calcilutite).

BR 4

In the hand specimen the rock is grey, friable and fine grained, with foramifera, flakes of mica and a little black pyrite clearly visible in an argillaceous base. The rock is not laminated and effervesces with cold $\frac{N}{10}$ HCl.

In thin section, this rock is composed of a base of pale grey-brown material, quartz grains and foraminiferal remains, together with some glauconite, biotite and other minerals. The grey-brown base, as far as can be determined, is made up of argillaceous material, finely divided quartz, tiny flakes of mica, a little felspar and possibly carbonate - small grains of black iron ore are scattered throughout. In one part of the section this base takes the form of ovoid pellets, with the large and small diameters averaging respectively 0.28 and 0.15 mm. As the pellets are slightly deeper coloured round the margin than towards the centre, and may be cemented locally by iron ore, their outlines are in places very clearly defined. Some of the pellets contain aggregates of a mineral with low relief and low birefringence which has a radial structure - this is probably chalcedony. It seems likely that these pellets may be a variety of coprolite, the name applied to the fossilised excreta of certain mud eating organisms.

Glauconite is not abundant. In places it is enclosed within the tests of foraminifera, but in many cases no trace of any enclosing organism can be seen. Not all foraminifera contain glauconite - some appear empty and others contain finely divided carbonate and argillaceous material. Occasionally, small grains of green glauconite can be observed whose boundaries, even under a magnification of 450, merge imperceptably into the surrounding argillaceous matrix. This of course, suggests derivation of the glauconite from the finely divided base. There is a fair abundance of green biotite scattered throughout the slide, but a careful search has failed to reveal any biotite which is definitely in the process of alteration to glauconite.

Angular quartz grains of average diameter 0.05 mm. make up 12 per cent of the rock. Pyrite is fairly abundant - it comprises perhaps 3 per cent of the whole - and is in the form of a local cementing medium between coprolite pellets, and as small grains scattered throughout the slide. A few foraminifera are replaced by pyrite. A little black iron ore and some red-brown iron stains are also present.

This rock is a silty, foraminiferal and coprolitic marl.

Jarosite ? Base Bed BR/4

In the hand specimen this rock is soft and friable, and is made up of a pale yellow mineral (which comprises apparently 60 per cent of the whole) black pyrite and a few grains of a lighter coloured mineral. The rock does not effervesce with acid.

Microscopically, about 40 per cent of the rock is seen to consist of a mineral which has been so impregnated and stained with limonite that it appears opaque and red-brown in reflected light. In places, where limonite staining is not pronounced, the mineral is translucent - it appears yellowish in colour, with high relief, strong birefringence and aggregate polarisation. This mineral may be jarosite, or some mineral closely related to it, but the degree of impregnation with limonite which it has undergone, renders microscopic identification uncertain.

Large, often euhedral, crystals of a colourless mineral with low birefringence and low relief make up possibly 45% per cent of the rock. This mineral may exhibit multiple twinning, has good cleavage in one direction, and is interleaved with a pale grey or neutral mineral with higher birefringence. The optical properties of the colourless mineral are as follows:

Elongation -ve
2V positive, about 65°
R.I. 1.518 - 1.529 as nearly as can be determined.

These properties show that the colourless mineral is gypsum. Some crystals have a diameter of up to 4 mm. - other smaller, perfectly euhedral crystals may be completely enclosed by the limonite impregnated mineral.

Associated closely with the gypsum is a pale, colourless to grey, flaky mineral with fair birefringence and relief greater than balsam. This mineral is uniaxial or nearly so, and is optically -ve. The extinction of these flakes is generally, but not in every case, parallel, while the elongation is positive. The mineral is probably alunite - it appears to occur in close association with the gypsum crystals.

About 10 per cent of the rock is made up of pyrite. This is in the form of aggregates, often with linear borders which seem to have been determined in some measure by the crystallising power of the gypsum.

This rock is a weathered alunite jarosite (?), gypsum rock.

A sample of a soft yellow mineral (W106) thought to be jarosite, was roughly analysed in 1947 by E.R. Segnit of the Cement Section, C.S.I.R.O. Fishermen's Bend, Melbourne. His results are as follows:

SiO_2	—	23.9
Fe_2O_3	—	16.5
Al_2O_3	—	6.2
CaO	—	.9
MgO	—	p.n.d.
H_2O at 113°	—	16.3
H_2O 7 113°	—	7.5
Na_2O	—	5.1
K_2O	—	Nil
SO_3	—	21.1
		97.7

Insoluble matter 26.9%

In explanation of his results, Segnit states that the mineral appears to be natrojarosite, mixed with earthy matter. He thinks the lime may be present as carbonate, while the result for sulphate may be too low. No potash could be detected with the flame photometer. The insoluble residue is considered to be chiefly quartz.

BR 5

This rock, which is grey and very friable, is made up of shell fragments and tiny foraminiferal tests with a little green glauconite and a few specks of mica. It exhibits no bedding or lamination in the hand specimen, and effervesces with cold $\frac{N}{10}$ HCl.

Under the microscope, this rock is composed mainly of foraminiferal tests and other fragments of organic origin together with angular quartz grains (average diameter 0.06 mm) some glauconite, pyrite and a little argillaceous material. Many of the foraminiferal tests have been well preserved and stand out clearly in thin section - the carbonate of which they are composed is grey and turbid. Other irregularly shaped fragments which vary in colour from grey to brown have been determined as the broken portions of shells and echinoid spines. A few colourless sponge spicules are also present. Many, but not all, foraminifera contain glauconite - on the other hand some glauconite can be seen which does not appear to have been enclosed within an organic structure. A few small grains of pyrite can be seen, often concentrated within a foraminiferal test. Carbonate makes up probably 80 per cent of the whole, quartz about 17 per cent and glauconite 2 per cent.

The rock is a silty, shelly, foraminiferal limestone (calcarenite).

"H" BR 6.

This rock is grey and fairly well consolidated, with no evidence of bedding or lamination in the hand specimen. It is fine grained and effervesces slightly with cold $\frac{N}{10}$ HCl.

In thin section, this rock is seen to consist mainly of even-grained crystalline carbonate (average diameter 0.05 mm.) together with lesser amounts of quartz, marcassite, glauconite and mica. Foraminifera are present, but the great majority of the carbonate, which comprises about 87 per cent of the slide, shows no evidence of immediate organic origin. Some of the foraminiferal tests enclose marcassite and a little dark red iron ore, probably haematite — none in this slide encloses glauconite. The origin of the small ovoid grains of glauconite which are present, is uncertain - they may have been derived from mica, which is scattered sparingly through the section in the form of green and brown biotite flakes. Never-the-less, a careful search throughout the slide has failed to reveal any mica which is partly changed to glauconite, and there is thus no direct evidence of such a transformation. Tiny patches of what appears to be an argillaceous impurity are scattered sparingly through the rock, but here again there seem to be no visible gradations into glauconite.

The aggregates of iron ore (probably marcassite) are often composed of grains with a radiating structure - in many cases the marcassite is partly surrounded by faint brown stains of ferric iron. Quartz is present as clear angular grains which form possibly 8 per cent of the whole - the only other mineral noted is an occasional grain of leucoxene.

This rock is a silty limestone (calcilutite).

BR 7

This rock is grey and very friable, and shows no bedding or lamination in the hand specimen. Small shell fragments, tiny specks of mica and a little pyrite can be seen in the fine grey base, which is apparently of calcareous and argillaceous nature. The rock effervesces with cold $\frac{N}{10}$ HCl.

In thin section the rock is made up of a yellow-brown base, organic remains, quartz, pyrite and glauconite. The organic remains consist mostly of broken foraminiferal tests - usually of colourless to somewhat turbid carbonate - and a few elongate or irregularly shaped, brown, turbid fragments derived from larger organisms. The yellow-brown base is very fine and is difficult to resolve into its components under the microscope - it seems to be made up mainly of argillaceous material, fine quartz, black iron ore and pyrite, mica and possibly felspar. Some finely disseminated carbonate is probably also present. Green glauconite, with aggregate polarisation, is scattered rather sparingly throughout the slide in the form of ovoid pellets. Occasional rare grains of glauconite which seem to grade into the yellow brown material are also present - these are not well defined and appear in places as small greenish patches. Foraminifera are numerous, but none in this slide seems to contain glauconite.

Angular quartz is fairly abundant as grains with an average diameter of 0.08 mm. Mica consists mainly of muscovite, green biotite and a few flakes of brown biotite. A little chlorite may be present, but this is difficult to distinguish from the small green glauconite patches - the only other mineral noted consisted of a rare grain of brown tourmaline.

The estimated composition of the rock is as follows:

Yellow-brown base	41%
Carbonate	33%
Quartz	22%
Pyrite	3%
Mica, glauconite	1%

This rock is a sandy, foraminiferal marl.

BR/7 Bed J

The rock is grey and somewhat friable, showing no lamination in the hand specimen and containing white shell fragments. It effervesces with cold $\frac{N}{10}$ HCl.

Microscopically, the rock consists of carbonate (82 per cent), quartz grains (15 per cent), and pyrite (3 per cent). The carbonate is colourless, cloudy or brown - most of the brown material obviously has an immediate organic origin and is present in the form of shell fragments and broken foraminiferal tests. The quartz grains, which are angular, exhibit remarkable uniformity of size - their average diameter is 0/06 mm. Pyrite is scattered throughout the carbonate as small irregular grains. Also present are a little green chloritic material, a few flakes of brown biotite and some angular grains of sodic plagioclase.

The rock is a silty, shelly, foraminiferal limestone (calcarenite).

Bed K BR 7

The rock is grey, with large red-brown patches due to iron staining, and is fine grained and fairly friable, with no discernable bedding. It effervesces only slightly with cold $\frac{N}{10}$ HCl.

Microscopically, the rock consists mainly of granular carbonate having no obvious organic structure and an average grain diameter of 0.05 mm. Quartz, which is quite angular, makes up only 1 per cent of the rock. Other minerals present in small quantity are black iron ore, pyrite, limonite, a little clay, and a few grains of a green mineral, probably glauconite.

The rock is a limestone (calcilutite).

Hard Bed 7 BR/12

The rock is white, fairly compact, partly iron-stained and exhibits no bedding or lamination in the hand specimen. The only mineral which can be distinguished with the naked eye is mica, which occurs sparingly as small flakes. The rock effervesces with cold $\frac{N}{10}$ HCl.

Under the microscope the rock is seen to consist of a finely crystalline mass of grey, somewhat turbid carbonate, together with foraminiferal tests, glauconite, pyrite and a little mica.

Foraminiferal tests represent only 2 per cent of the rock and are often completely filled with glauconite. Other glauconite is not enclosed within tests, and occurs as small grains which are bounded by crystalline carbonate. Glauconite, whether free or enclosed, seems liable to transformation into limonite.

Quartz, present as small angular grains with an average diameter of about 0.05 mm., makes up 4 per cent of the rock. Other minerals noted comprise muscovite and biotite as occasional small flakes, black iron ore as small grains, and limonite, mainly in the form of red brown stains which impregnate the carbonate in places.

The rock is a finely crystalline limestone (calcilutite).

BR/4

The rock is light grey, argillaceous and friable with no visible lamination in the hand specimen. It contains occasional fragments of bryozoa and shells together with foraminifera, quartz and a small amount of mica and green glauconite. The rock effervesces with cold $\frac{N}{10}$ HCl.

Microscopically, this rock consists mainly of foraminiferal tests, fragments of the solid parts of larger organisms and quartz grains. Also present are pyrite, glauconite, mica, a few sponge spicules and a brownish, earthy base which is difficult to resolve but apparently consists of very finely divided quartz, mica, carbonate and clay.

Many of the large carbonate fragments are grey and turbid; the abundant foraminifera tests, occasionally turbid, are generally somewhat clearer in appearance. The outlines of many foraminiferal tests are well defined, and these can be clearly seen acting as host to glauconite. In many cases each chamber of the foraminifera is completely filled with green glauconite. Possibly between 5 and 10 per cent of the tests are filled in this way - the remainder are empty or contain a filling of pale brown, earthy material which sometimes shades into pale green. Glauconite may be seen which is not enclosed by foraminiferal tests - this seems to grade from dark green glauconite proper to pale brownish material with a greenish tint.

A small proportion - less than 1 per cent of the rock - is made up of pyrite. In some places this mineral partly or wholly fills the chambers of foraminifera, and in other parts of the slide it occurs as isolated grains. Quartz as angular grains with a diameter of 0.05 mm., and a little felspar, probably otthoclase, are the only other minerals present.

The rock is made up in the following proportions : carbonate 78 per cent, pale brown earthy material 11 per cent, quartz 7 per cent, glauconite 2 per cent, pyrite 1 per cent, felspar and mica 1 per cent.

This rock is a silty, argillaceous, foraminiferal limestone (calcarenite).

Hard band (Lst.) in BR 14

The rock is grey-white and non-friable, and contains numerous white shell fragments and foraminiferal tests, together with a little green glauconite. It effervesces slightly with cold $\frac{N}{10}$ HCl.

Microscopically, this rock is seen to consist mainly of carbonate made up of shell fragments, foraminifera, bryozoa and other organic remains. Most carbonate is slightly turbid, but a little, chiefly in the form of fillings enclosed in foraminiferal tests, is colourless with good rhombic cleavage. Brown, generally sub-rectangular, fragments of somewhat turbid appearance, probably represent the broken remnants of the hard parts of larger organisms.

Glauconite, as green ovoid grains which are often clearly enclosed within foraminifera, make up about 1 per cent of the whole. Angular quartz grains, of average diameter 0.1 mm., also make up 1 per cent.

Other minerals present are a few grains of pyrite, a little kaolin and limonite, and some small grains of a brown mineral with high relief and high birefringence, which may be sphene.

This rock is a shelly, foraminiferal limestone. (calcarenite)

Bed "L" at base BR/19

The rock is white but stained orange by iron oxide. It is fairly friable, unlaminated, fine-grained and contains a few shell fragments - the specimen effervesces slightly with cold $\frac{N}{10}$ HCl.

Under the microscope the rock consists of a grey, turbid mass of finely divided carbonate, slightly iron stained in patches, and containing angular quartz grains, foraminiferal tests and a few shell fragments. Organic remains form less than 5 per cent of the whole. The tests contain material, apparently mostly carbonate with a little clay, which has been stained brown - this stain often extends beyond the walls of the test to form irregular patches in the surrounding rock. Other brownish patches, which in places may have cores of green, chloritic or glauconitic material are scattered throughout the rock - these do not appear to have been enclosed in foraminifera in all cases.

Quartz grains, which are angular and have an average diameter of 0.05 mm., make up 10 per cent of the rock. A little muscovite and a few small grains of black iron ore are the only other minerals present.

This rock is a silty limestone (calcilutite).

B ? The label on this rock is not clear - only the initial letter - B - can be deciphered.

The rock is friable, argillaceous and red-brown due to iron staining. It effervesces with cold $\frac{N}{10}$ HCl. Occasional tiny specks of mica and small foraminifera can be seen with the naked eye.

In thin section, this rock is seen to be composed dominantly of quartz, together with felspar and a pale brown, somewhat iron stained, cementing base. This base, particularly in view of its stained appearance, is difficult to resolve into components under the microscope - it seems to consist of clay and very finely divided quartz, mica and carbonate.

Foraminiferal tests are present, but are not common, while occasional flakes of greenish mica are scattered throughout. One grain of red rutile was seen.

Quartz, as angular to subangular grains with an average diameter of 0.05 mm., makes up 65 per cent of the rock. Felspar makes up possibly 5 per cent, and the remainder consists of cementing material.

The rock is a marly siltstone.

"A" RP/1

The rock is grey, slightly ironstained in places and somewhat friable. Green glauconite, quartz grains and foraminiferal remains can be seen with the naked eye. The specimen, which effervesces with cold $\frac{N}{10}$ HCl, shows no trace of bedding or lamination.

Under the microscope, this rock appears somewhat coarser than those described previously, and consists mainly of carbonate (93 per cent) and angular quartz grains. The carbonate is generally grey and turbid, and is made up of broken fragments of organic origin, often with good cleavage, and many clearly defined foraminiferal tests. Irregular clots of a yellowish-green mineral with aggregate polarisation, which is partly converted to limonite, represent glauconite. These make up about 1 per cent of the rock, and are usually found enclosed in foraminiferal tests. A few patches of grey-green material which are difficult to resolve under the microscope, probably consist of finely divided carbonate, clay and mica.

The quartz grains, which are quite angular, have an average diameter of 1 mm. - innumerable small cavities, generally less than .01 mm. in diameter, are scattered throughout. These cavities contain a gas-liquid mixture, the fluid nature of which is clearly demonstrated by small bubbles which can be seen moving from side to side of their enclosure, presumably under the influence of changing temperature conditions and small vibrations. Quartz makes up possibly 5 per cent of the rock.

This rock is a foraminiferal, sandy limestone (calcarenite).

"B" in RP/3

In the hand specimen, this rock appears pale orange-brown, due to uniform staining by iron oxide - it is fine grained, slightly porous, non-friable, is not laminated and effervesces in cold $\frac{N}{10}$ HCl. Tiny foraminiferal tests can be seen with difficulty by the naked eye.

Under the microscope, 94 per cent of the rock is seen to be composed of grey, partly iron-stained carbonate - the carbonate is made up of the calcareous skeletons of various organisms including the tests of foraminifera, many of which are well preserved and clearly defined in thin section. Occasional poorly defined patches of turbid grey-brown material within the tests, which cannot be resolved under the microscope, probably represent very finely divided clastic impurities, mainly argillaceous in nature. This material in places assumes a pale but dirty green colour, and is presumably the precursor of glauconite.

Glauconite, together with secondary limonite, forms 5 per cent of the rock. This mineral seems to be almost invariably enclosed within a foraminiferal test, or within the pores of some organic skeletal remains. All stages can be seen in the conversion of glauconite to limonite, as follows :

(1) pale yellow-green glauconite with aggregate polarisation.

(2) a greenish brown mineral with masked polarisation colours. This mineral appears dull red-brown in reflected light.

(3) an opaque mineral which is red-brown in reflected light - limonite.

A few tiny grains of pyrite are occasionally associated with the glauconite.

Quartz is sparsely distributed throughout the rock in angular grains with an average diameter of only 0.05 mm. - this contrasts with the foraminifera which range up to 0.5 mm. and average about 0.3 mm. Quartz comprises probably less than 1 per cent of the whole.

This rock is a glauconitic, foraminiferal limestone (calcarenite).

Bed "M" Bird Rock

The rock is grey-white and fine grained with pale red-brown patches due to the oxidation of ferrous iron. It is slightly friable, contains white foraminiferal tests which are clearly visible to the naked eye, and effervesces with cold $\frac{N}{10}$ HCl.

Microscopically, the rock is seen to be made up of a finely-divided, grey, somewhat turbid mass of carbonate, probably with a little argillaceous impurity, containing quartz grains, a few shell fragments, patches of limonite and some clearly defined foraminiferal tests. Many of the red-brown limonite patches surround a darker core which resembles a foraminifer in shape - this together with the fact that small portions of some patches have a yellow-green tint, suggests that at least some of the limonite is secondary after glauconite.

Quartz is very angular and is made up of grains having an average diameter of the order of 0.05 mm. - these grains, with a little chalcedony and felspar, comprise possibly 5 per cent of the rock. Also present are a few grains of black iron ore and occasional flakes of muscovite.

The rock is a foraminiferal, silty limestone (calcilutite).

Bed "N" Bird Rock

This rock is fine grained, grey-white but stained pale orange in patches, slightly friable and unlaminated. It effervesces only slightly in cold $\frac{N}{10}$ HCl.

In thin section, the rock consists of a finely granular mass of carbonate and angular quartz grains. The carbonate, which shows no sign of organic structure and occurs as grains with an average diameter of 0.05 mm., makes up about 90 per cent of the rock. Some of the grains are in the form of rhombohedra. Quartz, angular and similar in grain size to the carbonate, makes up 5 per cent of the whole.

A few small, brownish-green, ovoid grains which appear to

have aggregate polarisation probably represent glauconite which has been partly converted to limonite. Other limonitic stains and patches are scattered throughout the slide, while a few grains of black iron ore, a little green biotite and some colourless muscovite are also present.

This rock is a silty limestone (calcilutite).

FB3 Type Section Torquay.

This rock is medium grained, very friable and light grey. It is made up mainly of shell fragments, foraminiferal tests and quartz grains, with occasional small greenish patches of glauconite. The rock effervesces with cold $\frac{N}{10}$ HCl.

Under the microscope the rock is seen to consist essentially of grey turbid carbonate derived from shell fragments, foraminiferal tests and other organisms, together with patches of grey-brown, finely divided material, angular quartz fragments and pellets of glauconite. The grey-brown material, which comprises possibly 7 per cent of the rock, is made up as far as can be determined, of clay, finely divided quartz, minute mica flakes and possibly carbonate, the whole often stained lightly with red-brown iron oxide. Occasional small irregular patches of pale yellow-green glauconite are scattered throughout the argillaceous matrix, into which they seem to grade imperceptibly, suggesting they have been derived directly from the matrix. Other glauconite is found as ovoid pellets with a long diameter of up to 1 mm. and a short diameter of up to 0.6 mm. A little glauconite is found in the skeletons of bryozoa and the tests of foraminifera. This glauconite may occupy all chambers of the foraminiferal test, or only the outer chambers. The pressed apart walls of some of the tests containing glauconite suggest that larger grains may once have been similarly encased. In many cases careful searching has revealed no evidence of fragmentary test walls. The glauconite of this rock varies in colour between yellow-green and dark yellow-green - probably all varieties show aggregate polarisation, but this is difficult to see in some examples with very low birefringence. Double refraction seems to vary between very low and fair (apparently second order) but is generally hard to determine because of the masking effect produced by the colour of the mineral. Glauconite makes up 2 per cent of the whole.

Angular quartz makes up about 5 per cent of the rock - the grains are fairly large, with an average diameter of 0.5 mm.

The rock is a sandy, argillaceous, shelly, foraminiferal limestone (calcarenite).

FB4 Type Section Torquay

The rock is grey and friable, and contains small gastropods, foraminiferal tests, green glauconite pellets, a few small quartz grains and occasional specks of mica. The specimens contain a few very small, red-brown patches of limonite and exhibits no bedding or lamination - it effervesces with cold $\frac{N}{10}$ HCl.

Microscopically, this rock is seen to consist mainly of carbonate - made up chiefly of shell fragments and foraminiferal tests - together with smaller amounts of glauconite, pyrite, limonite and muscovite. The material of which the foraminiferal tests and shell fragments are composed varies in appearance from grey and turbid to pale brown or colourless. A pale grey base, made up probably of

very finely divided mica, carbonate, quartz and clay with limonite and pyrite specks scattered throughout, comprises 15 to 20 per cent of the whole.

Glauconite forms 1 per cent of the rock and is often enclosed within foraminiferal tests, which may have their walls pressed apart or broken. In many cases no enclosing test walls can be seen, and careful examination has failed to reveal even small portions of test wall fragments. A few small grains, when examined under high power magnification (X450) seem to consist of green glauconitic cores which merge gradually into the grey argillaceous base. This suggests derivation of at least some of the glauconite from the base. Other grains with fairly well defined boundaries resemble in shape many of the mica flakes which are present. This resemblance is fairly strong where the mineral has the rough or slightly mammillated surface of glauconite and has practically no double refraction. No definite example of the conversion of biotite can be seen i.e. there seems to be no example of a grain which is part biotite, part glauconite. This may perhaps be due to the fact that biotite is of the green variety, which would prevent any alteration to green glauconite from being particularly noticeably in small flakes. Glauconite often contains small flakes of mica and tiny quartz grains, which could indicate either derivation from the finely divided matrix, or derivation from mica which expanded during the process, absorbing surrounding clastics.

An opaque mineral with a metallic lustre and bronze-yellow colour in reflected light which occurs as irregular grains often having a radial structure, is probably marcassite. One marcassite aggregate is enclosed within the test of a foraminifer, while some foraminifera and shell fragments have been replaced by the mineral. Almost without exception, marcassite is surrounded by an aureole of red-brown material, apparently carbonate which has been discoloured by iron-rich solutions emanating from the marcassite.

Small specks of haematite, making up about 2 per cent of the rock, are scattered uniformly throughout the slide. Angular quartz with an average diameter of only 0.02 mm. represents probably less than 1 per cent. A few small black iron ore grains, occasional flakes of biotite and a little felspar comprise the only other minerals present.

The rock is an argillaceous, shelly and foraminiferal calcarenite.

A1 (specimen1)

In the hand specimen the rock has an overall grey-green colour: it is slightly friable, fairly weathered and somewhat vesicular. Occasional serpentinous relicts of olivine phenocrysts, together with abundant white, angular grains of tridymite are set in the dark, fine grained groundmass. This sample is in the form of a small cobble, and apparently forms part of a volcanic agglomerate - a small portion of the grey matrix of the agglomerate is attached to the cobble.

Under the microscope, the rock is seen to be porphyritic with completely altered olivine phenocrysts of average diameter 1 mm. in a fine grained groundmass. Tridymite is abundant as a colourless, clear mineral which apparently occupies cavities within the rock.

The presence of olivine phenocrysts in the original rock can be inferred from the characteristic, generally euhedral, serpentinous pseudomorphs which can be seen. The serpentine, which varies from reddish-yellow to yellow-green, is made up of two varieties. The majority of serpentine is lamellar and non-fibrous and probably represents bowlingite - a small proportion occurs as cross-fibre veinlets with pronounced pleochroism from pale green to darker yellow-green or

brown - this is probably xylotile. The two minerals are intimately associated. In places, however, the phenocrysts have altered to pale green antigorite.

The groundmass consists essentially of plagioclase, pyroxene and serpentine. Plagioclase occurs as a network of lathes having a composition which may be designated $Ab_{38}An_{62}$. The average length of these lathes is 0.1 mm. Pyroxene is present as smaller, subhedral, purplish, faintly pleochroic grains which strongly resemble titan-augite and show incipient alteration to pale green bastite. Black iron ore occurs as minute grains and locally as a network of minute lathes. No volcanic glass can be seen, but this may have been the precursor of much of the abundant, pale green serpentine (probably antigorite) which fills the interstices between the felspar lathes.

Tridymite, which seems to occupy cavities in the groundmass, occurs as angular aggregates, often with irregular outlines which are oval in general shape. The maximum diameter of these aggregates commonly approaches 2 mm. The mineral is colourless, has poor relief with n < balsam, very low birefringence and is characterised by abundant wedge-shaped twins. Some of the aggregates may be said to have a tile structure when observed under crossed nicols. Interference figures can be obtained on some of the larger crystals, and indicate a positive 2V of 30° to 40°.

The composition of the rock, estimated visually, is as follows :

Groundmass (Serpentine 39%, plagioclase 16%, augite 10%, magnetite 10%.)	75 per cent.
Tridymite	22 " "
Serpentine pseudomorphs after olivine	3 " "

The rock is a serpentinised olivine basalt containing pockets of tridymite, probably as fillings of what were once vesicles. The specimen consists of a small cobble embedded in the matrix of a volcanic agglomerate.

A1 (specimen 2)

The hand specimen is grey, friable and unlaminated - it consists mainly of soft, pale brown or grey material together with chalcedony and opal. The rock is apparently the tuffaceous matrix of a volcanic agglomerate.

This rock, which is light grey in the hand specimen, assumes an overall greenish colour when cooked in balsam preparatory to making a thin section. Under the microscope, it is seen to consist mainly of fairly uniform, green non-pleochroic material which is isotropic or weakly doubtle refracting, and has a low relief within slightly greater than balsam. The material shows its greatest tendency towards weak double refraction in places where the colour is very pale green or yellowish. It is not certain what the green matrix of this rock represents - it may be a variety of the mineraloid palagonite, which is a hydrogel formed by the alteration of basaltic glass.

Numerous spherulites, generally outlined by a brown or green borders and commonly elongated in a constant direction, are scattered through the rock. The spherulites seem to be composed of two minerals. One variety consists of a colourless fibrous mineral with low relief and weak double refraction which resembles chalcedony, and the other variety is made up of radiating fibres of a brown pleochroic mineral with fair birefringence which may be the serpentine xylotile. A few chalcedonic

spherulites attain a diameter of 0.6 mm.

Remnants of euhedral crystals, probably of some ferromagnesian mineral, are present : these are entirely replaced by brown, pleochroic, radial aggregates of xylotile. Chelcedony and opal are common and make up probably 15 per cent of the slide. The chalcedony, which is colourless, occurs in what appear to be colloform crusts which have been infilled with grey, isotropic opal. Euhedral to subhedral crystals of labradorite attain in places a length of 0.5 mm. and are present either as aggregates or individuals.

The rock is the matrix of a volcanic agglomerate.

W98

The rock has a grey, slightly vesicular matrix containing angular fragments of white or pale green, cryptocrystalline material which measure up to 5 mm. in diameter. A dark, finely laminated fragment of shale is also contained in the specimen.

Under the microscope, the rock is seen to consist essentially of colourless or pale green, glassy and cryptocrystalline shards and larger fragments which are embedded in a brown, amorphous, isotropic matrix. The brown matrix probably represents a mixture of ash, argillaceous matter and glassy material; it commonly contains angular fragments of quartz measuring up to 0.1 mm. in diameter and crystallites of plagioclase.

The pale, cloudy, cryptocrystalline fragments in some cases contain numerous incipient plagioclase crystals, which may be arranged either as a network, or in a lineat manner suggestive of flow structure. Other fragments contain aggregates of larger, euhedral to subhedral plagioclase crystals which may attain a lenth of 2 mm. - this plagioclase is usually of the variety labradorite. Spherulitic aggregates of chalcedony are also present in a few places. The larger cryptocrystalline masses and shards are commonly surrounded by a brown aureole which is appreciably darker than the majority of the brown matrix.

Also present in the rock are a few small grains of a green non-pleochroic mineral which is either isotropic or weakly double-refracting. Grains of black iron ore and rare pyrite are scattered throughout.

This rock is a fine volcanic breccia containing mud fragments.

W107

The rock is light grey and fairly friable, being composed mainly of carbonate grains and a little quartz. Heavy mineral grains are scattered throughout the specimen, and these are concentrated locally in a black seam of 1 cm. thickness. The rock effervesces strongly in cold $\frac{N}{10}$ HCl.

In thin section, the rock is seen to consist mainly of carbonate. The carbonate, which comprises 68 per cent of the slide, is made up of foraminferal tests, finely divided crystalline material and a few shell fragments. Angular quartz grains of average diameter 0.2 mm. make up 6 per cent of the rock. A little chalcedony is present.

Heavy minerals are abundant, and with the exception of garnet, which is rare, the grains are very well rounded and somewhat smaller in size than the quartz. Their average diameter is of the order of 0.1$\frac{5}{}$ mm.

A bromoform separation has been carried on a representative portion of the sample, with the following results:-

Per cent by weight of heavy minerals in the sample	44

Per cent composition by weight of the heavy residue

Ilmenite		33
Magnetite		23
Rutile		23
Zircon		20
Others	(Tourmaline, kyanite, garnet, staurolite, topaz, monazite, hornblende, limonite, leucoxene.)	1

The rock is therefore a foraminiferal sandy limestone (calcarenite) with a concentration of heavy minerals.

A Note on the Origin of Glauconite in Rocks of the Janjukian Type Section of Victoria

In thin section, glauconite from the Janjukian type section of Victoria varies from pale yellow-green to almost apple-green; it has aggregate polarisation, and its birefringence is generally masked by the original colour of the grain. Pellets and grains of the mineral are commonly heterogeneous, and may contain fragments of quartz, mica and various iron ores. The heterogeneous nature of the glauconite, together with its aggregate polarisation, have made almost impossible an accurate determination of the three refractive indices. The refractive indices have been found to occupy a range between the limits of 1.575 and 1.602 - these figures are lower than those usually quoted (Winchell, 1946 and Schneider, 1927) and fall between those given for the Lakes Entrance glauconite and the low index glauconite from South Australia (Dallwitz, 1948).

Glauconite from the Janjukian samples is not constant in optical character, but apparently represents stages in the transformation of some pre-glauconitic progenitor to true glauconite. All glauconitic material shows a strong disposition to alteration to limonite, and the following stages can be seen:-

(1) Green glauconite with aggregate polarisation;

(2) A brown mineral with a greenish tint, which has strongly masked birefringence. This mineral appears dull red-brown in reflected light.

(3) A black opaque mineral - limonite - which is red-brown in reflected light and which may be surrounded by stains of similar colour.

Glauconite from these samples may be broadly divided into two classes as follows:-

(1) This class comprises glauconite which is enclosed within the tests of foraminifera, or within cavities in other organisms with hard skeletons, or glauconite which was once clearly enclosed by some organic covering. The glauconite may completely fill each chamber of a foraminifer, or may occupy only the outer chambers. Many foraminifera containing glauconite appear in thin section as completely preserved and well defined tests, whereas others are represented by fragments of broken test walls.

(2) This class of glauconite comprises grains which are not enclosed within the hard framework of any organism, and some which may not have been enclosed during any stage of its formation. In this category, then, is glauconite as oval pellets, glauconite with fairly irregular shape but clearly defined boundaries, and glauconite with indefinite boundaries which seem to grade imperceptably into the surrounding argillaceous material. This latter, poorly defined glauconite usually occurs as small patches which are scattered rather sparingly throught the rock - they are best observed and described under fairly high power magnification (X450).

Galliher (1935) has shown conclusively that glauconite in Monterey Bay, California, has formed from brown and green biotite. Glauconite forms round the edges of flake, and by working in toward the centre, slowly converts the whole biotite grain. It also attacks biotite along the cleavage, causing the flakes to split slowly apart. With glauconitization comes a great increase in volume, so that, as the flakes are pushed apart, the whole grain assumes a "concertina" structure. Of 800-1000 grains which Galliher described from Monterey Bay, he noted only one which was enclosed within a foraminifer.

Shepard (1948), noting that glauconite is an indicator of slow deposition, states that, whatever its origin, it is quite certainly an indication of the failure of sediments to cover the deposits during the time of their alteration. As the mineral is found in abundance in the tests of foraminifera, he is inclined to the view that biotite may not be its most important source. Both Shepard and Galliher refer to the pioneer work of Murray and Renard (1891), who emphasised the importance of the alteration of mud in foraminiferal tests to give glauconite. Murray and Renard observed transitions from yellowish-brown mud to glauconite, but believed it improbable that any glauconite was formed from mud in the free state, that is, mud which was not enclosed with foraminifera. Galliher explains the occurrence of glauconite within broken foraminiferal shells as being due to small flakes of biotite which have been sifted into foraminifera, and which have undergone considerable expansion during their transformation into glauconite. This hypothesis does not seem to explain satisfactorily numerous examples of coiled tests which are compplетely filled with glauconite, and which have both the outer walls and the inner walls separating the chambers, perfectly preserved. Galliher states that, in many cases, the expansion and growth of glauconite as it forms from biotite, causes the final product to assume shapes superficially resembling the casts of foraminifera.

Takahashi and Yugi (1929) have described stages in the formation of glauconite from grey, coprolitic mud - under high maginification the grey mud is revealed as a heterogeneous complex consisting of extremely fine fragments of quartz and felspar with a dark yellow or brownish, "clayey" matrix.

Biotite found in samples from the Janjukian of Victoria is mainly green, which renders difficult any investigation into its possible decomposition to green glauconite. Careful searching under high magnification has failed to reveal any grain with a core of biotite surrounded by a periphery of glauconite. Furthermore, no evidence of the "concertina" structure of Galliher has been seen. At the same time, some pale green glauconite grains with a mamillated surface, and with well defined boundaries, resemble adjacent biotite flakes in shape. These pale green grains have a very low birefringrence, and may perhaps have been derived from biotite. Thus although no direct evidence of the conversion of biotite to glauconite can be presented, it seems not impossible that

a little at least of the glauconite may have come from this source.

Glauconite which is present as occasional, small, poorly defined patches which appear to grade imperceptibly into the surrounding, pale, yellow-brown, argillaceous base, is probably not secondary after mica. The so-called argillaceous or muddy matrix is invariably difficult to resolve into its components under the microscope - it generally seems to be made up of yellow, brown or grey clay and finely divided quartz, together with mica and possibly a little felspar and carbonate. Minute grains of pyrite and black iron ore may be abundant locally, and the whole may be stained to a varying degree by iron oxide. It should be borne in mind that the small glauconitic patches found in this base may have been formed initially within foraminifera, and may have been subsequently washed out of the tests or otherwise dispersed. Nevertheless, the lack of definition of some of the boundaries of the glauconite grains may suggest that the mineral formed as a core which has slowly grown outward by some process of glauconitization. If this is so, it must be assumed that the clayey matrix itself was the precursor of the glauconite; the heterogeneous nature of much of the glauconite, which commonly contains small grains of mica, quartz and iron ore, strengthens this view.

Some glauconite, after concentration and separation from the crushed rock by panning, appears as grains which resemble very strongly the internal casts of foraminifera. When mounted in liquid and studied under the microscope, many grains show no evidence of a surrounding test wall. It is not certain what process has removed the wall. Miss Crespin has shown the writer various glauconite casts of foraminifera from the Upper Cretaceous of Cardabia; some of these are partly surrounded by test walls which seem to be peeling off. If the walls have been removed during transportation along the sea floor, it is difficult to explain the perfectly preserved shapes of the glauconite surfaces. It is unlikely that the walls themselves have been glauconitized, for in some cases sections of pellets having no outer wall, contain clearly preserved inner walls which once separated the individual chambers of the foram. It is not generally thought that calcareous test walls are prone to alteration into glauconite, and it is difficult to see on chemical grounds, how this could happen. The walls may, perhaps, have been pushed apart by the expansion of the argillaceous material during glauconitization, and may then have been removed; any such expansion must necessary have been slight, for the final product is commonly a perfect internal cast of the test.

Ovoid grains without surrounding walls or internal subdividing walls may have been formed within the test of a single-chambered organism. On the other hand, in view of the apparently coprolitic nature of some of the mud in sample BR4, it is possible that a little of this glauconite represents coprolite which has been transformed.

The origin of glauconite has been the subject of many interpretations. It has been described by various authors as a mineral which is secondary after mica, coprolitic pellets, and mud enclosed within foraminifera, respectively. A little glauconite from the Janjukian type section of Victoria may, perhaps, have been derived from mica, but much has probably come from mud, both inside and possibly outside foraminifera. Where mud is converted to glauconite, it seems that an environment involving some form of imprisonment in an organic structure is very favourable, but is perhaps not always necessary in every case. It is of interest that Murray and Renard believed decaying organic matter enclosed within the tests played a large part in the transformation of mud to glauconite, and Schneider also postulated the necessity of an environment involving organic matter.

It is tentatively suggested that, on the basis of origin, at least two classes of glauconite may be recognised - glauconite formed from mica and glauconite formed from mud. It is further suggested that the refining or seiving undergone when mud is filtered into the chambers of foraminifera, or is passed through the digestive tracts of mud-eating organisms, together with the subsequent compaction it undergoes in each case, favours the formation of glauconite. The mineral has been described above occurring as small patches which have no obvious relationship to any organism. Thus, unless it can be demonstrated that the addition of some organic compound is a necessary prerequisite to the formation of glauconite, there seems no conclusive reason to assume that free mud, suitably refined and compressed by some means during the normal process of slow sedimentation, can not be similarly transformed.

(J. E. Glover).

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