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PAPER 69-17

PERMO-CARBONIFEROUS STRATIGRAPHY AND STRUCTURE OF CENTRAL PRINCE EDWARD ISLAND

(Report and 5 figures)

L. Frankel and G. H. Crowl

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L. Frankel and G. H. Crowl

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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ABSTRACT

The Permo-Carboniferous and perhaps younger rocks consist mainly of sandstone, with lesser amounts of conglomerate, mudstone breccia and mudstone and are assignable to subunits A2 and A3, and unit C of the stratigraphic sequence established in southeastern Prince Edward Island. Subunit A1 and unit B have not been seen in the map-area. Unit C and subunit A3 are unconformable.

The major structure is a northeastward plunging syncline whose axis seemingly parallels those of Gallows Point anticline and Kilmuir syncline lying 16 and 24 miles respectively to the southeast.

Faults bound a complex graben or tilt-block structure trending northwest-southeast across the central part of the island. This faulting occurred after the deposition of unit C.

PERMO-CARBONIFEROUS STRATIGRAPHY AND STRUCTURE OF CENTRAL PRINCE EDWARD ISLAND

INTRODUCTION

The primary purpose of this report is to describe the bedrock lithology, stratigraphy and structure of Rustico map-area and to relate this information to known stratigraphic and structural trends in other parts of Prince Edward Island. Included, also, are some data on Malpeque, Summerside, and Charlottetown map-areas which were collected by L. Frankel for the provincial government, during an assessment of the volume of calcareous sediment available for conversion to agricultural lime.

The determination of structural trends in Prince Edward Island is difficult because the exposed rocks are complexly crossbedded and dips are low, usually 5 degrees or less. Adding to these obstacles is the dearth of subsurface information, particularly data on the distribution of salt deposits whose local movements could affect the island's structure and the surface distribution of the various rock units.

The information presented in this paper is sketchy and must be considered of reconnaissance nature only. It was incidentally gathered while the writers were primarily concerned with the mapping of the surficial deposits of the Rustico map-area. Frankel's[1] work was done in 1960 and 1961, and Crowl's[2] in 1962 and 1964.

The writers have greatly benefited from their association with V.K. Prest, Geological Survey of Canada, who has mapped the surficial geology and made observations on the lithology and structure of other parts of the island. They are also grateful for the assistance given by the late B.G. Rogers and by P.A. Murnaghan, both of the Department of Industry and Natural Resources of Prince Edward Island, and many other government officials and residents of the island.

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[1] L. Frankel is presently a Professor of Geology at The University of Connecticut, Storrs, Connecticut.

[2] G.H. Crowl is presently a Professor of Geology at Ohio Wesleyan University, Delaware, Ohio

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TOPOGRAPHY AND ROCK EXPOSURES

Rustico map-area, covering approximately 350 square miles, is in central Prince Edward Island. Its northern border lies along the Gulf of St. Lawrence and extends from Tracadie Bay to just west of New London Bay. It is bounded on the east by Mount Stewart map-area (Crowl, 1960, in press), on the south by Charlottetown map-area (Prest, 1964), and on the west by Summerside map-area. To the northwest is Malpeque map-area.

Over most of the eastern two-thirds of Rustico map-area there is a gently rolling topography with elevations rising to a little more than 250 feet and local relief averaging 100 feet. Rivers are about 2 miles apart, have few tributaries and most of them flow north into the Gulf of St. Lawrence. A poorly developed dendritic drainage pattern is seen over most of the region. Till and glaciofluvial sediments, generally less than 10 feet thick, mantle the upland and lowland surfaces. Bedrock exposures are rare and are only locally seen along the coast and in road-cuts and other excavations. In Charlottetown map-area, the topography is similar but rock exposures are more numerous.

In the more hilly western third of Rustico map-area altitudes increase to over 450 feet and the highest elevations are in the vicinity of Hartsville and Stanchel; local relief commonly exceeds 250 feet. The rivers are about a mile apart and they have many tributaries. The valleys are narrow and their walls usually are steep. Over much of the area, an angular to subangular drainage pattern is developed. In this region, where the surficial cover is thin or commonly missing, bedrock is almost everywhere seen. To the west and northwest, in Summerside and Malpeque map-areas, elevations gradually lower and bedrock exposures become less abundant.

PREVIOUS WORK

Structure[1]

The sketchy and generalized data presented below constitute the bulk of the available structural information on north-central Prince Edward Island. Little is yet known about this and many other parts of the island because of the paucity of outcrops away from the coast in many areas and the complex crossbedding which masks the true attitude of the rocks.

Gesner (1846) described the rocks along the coast from New London Harbour to Richmond (Malpeque) Bay as having variable dip and being horizontal in many places. Later, Dawson and Harrington (1871) noted that the strata from Darnley to New London are horizontal, and that to the west of New London denudation of strata seems to have been more extensive than to the east. They also considered Cape Tryon to be on the west flank of a syncline which contains rock younger than most of that in the more westerly areas. A geological cross-section in this report (also reproduced in Dawson, 1878) shows the rocks at Rustico to be horizontal.

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[1] For the location of some folds and uplifts described by earlier workers, see Figure 1.

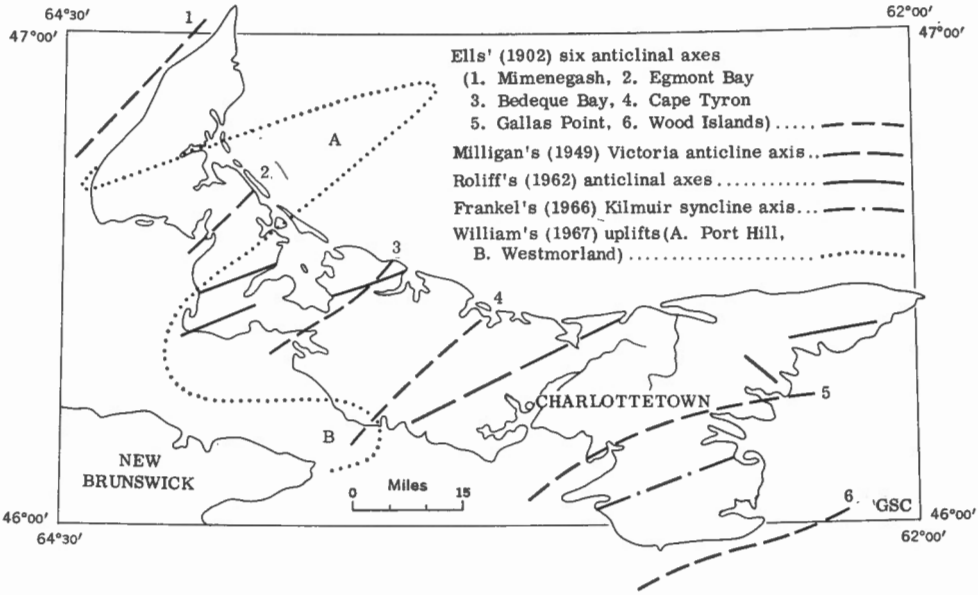

Figure 1. Structural features of Prince Edward Island.

In 1872, Dawson further speculated that the folds on Prince Edward Island were extensions of those in New Brunswick and Nova Scotia. This idea was expanded by Ells, who initially (1884) postulated four and later (1902) six anticlinal axes extending from the mainland. Two are of interest to this report: one extending from Cape Bald, New Brunswick through Bedeque Bay and Summerside to Cape Tryon, and the other, from Cape Tormentine, New Brunswick through Tryon and thence northeast to Rustico Bay.

Milligan (1949) confirmed the position of the Summerside to Cape Tryon axis, but questioned that of the more easterly structure (which he called the Victoria anticline). He suggested that it passes near Milton Station and that Covehead Road is not far off this axis. Milligan also pointed out that the position of the synclinal axis complementary to these folds is vague. He speculated that this "... axis bends northward from Fredericton towards Stanley Bridge, and then eastward again towards Orby Head, with a parallel minor anticline near St. Ann's. This would be separated from the Victoria anticline by a down-folded area between Ebenezer and Covehead" (1949, p. 14).

Age of Strata

The exposed rocks on Prince Edward Island have been ascribed by various writers to the Carboniferous, Permo-Carboniferous, Permian, and Triassic periods. Because the age determinations in one locale greatly influenced thought about other areas, the historical review cannot be restricted to one map-area, but must encompass the entire island. In this report pertinent work done mainly after 1961 is discussed. Earlier investigations are noted in Frankel (1966).

As a result of the recent increase of field work and subsurface exploration on the island, animal and plant remains have been found which aid in dating rocks from scattered locales. Many of these fossils confirm the age speculations of earlier workers, but none suggests the presence of Triassic rocks.

In northwestern Prince Edward Island, at Little Miminegash Pond, Carbonita inflata (Jones and Kirkby), an ostracod which occurs in Pictou deposits in other parts of the Maritimes, was found in surface rocks (Copeland, 1957). At Port Hill, Wellington Station, and MacDougall, a study of drilling samples revealed Stephanian and/or Westphalian spore assemblages at several levels. At MacDougall (Imperial MacDougall No. 1), a Stephanian assemblage was found within 20 feet of the surface, but at Port Hill (Imperial Port Hill No. 1) and Wellington Station (Imperial Wellington Station No. 1), similar assemblages were not encountered above 1,720 feet (Barss, et al., 1963).

At Gallows Point (Gallows Pt.-Earnscliffe No. 1), a Permian spore assemblage was found 330-350 feet from the surface, and on Governor Island, Stephanian spores were found in surface rocks (Barss, et al., 1963). In the exposed rocks along the north and east shores of Hillsborough Bay, vertebrate remains diagnostic of the Lower Permian (Wichita-Clear Forks) were found at scattered locales (Langston, 1963; Frankel, 1966).

Bedrock and excavated boulders at Spring Valley and Irishtown, close to French River where Bathygnathus borealis Leidy was discovered about 1845, yielded vertebrate fossils suggestive of the Lower Permian (Langston, 1963).

These recently-found fossils firmly establish that the age of the rocks differs from place to place on the island.

A detailed lithologic study of southeastern Prince Edward Island (Frankel, 1966) has shown that there are 3,500 feet of Lower Permian fossil-bearing beds, and that they are overlain by almost 2,000 feet of post-Lower Permian sedimentary rocks whose age is not yet known.

LITHOLOGY

Bedrock in central Prince Edward Island consists mainly of sandstone which accounts for 70 to 75 per cent of the sedimentary rock. Other coarse-grained rocks, such as pebbly sandstone, conglomerate, and mudstone[1] breccia, are present in small amounts, and together they constitute less than 10 per cent of the materials. Mudstones account for 15 to 20 per cent of the sediments. Some of these rock units are shown on Figure 2.

Colour is the most variable character of these rocks. Most of them are reds of diverse hue and chroma, but greys, purples, greens and browns also are seen.

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[1] As used in this report, the term mudstone includes siltstone, claystone and shale. In almost all locales, the fine-grained rocks lack the fissility required by most investigators for use of the term 'shale'.

Sandstone

The sandstones differ to some extent in minor characteristics (colour, manganese oxide, carbonate content), but in most respects (mineral composition, shape and sorting of component grains, crossbedding) they are similar. All may be considered as arkose or feldspathic sandstone as defined by Pettijohn (1957).

The texture of the sandstones varies from very fine to coarse grained. The grains are predominantly angular to subangular; subrounded to rounded grains are found rarely. Sorting varies from poor to moderate. The fabric normally is isotropic; however, where there is an abundance of mica, a preferred orientation is visible even in hand specimens.

The assemblage of minerals is restricted to a few types. Quartz is the dominant mineral. Feldspar (orthoclase, microcline, and sodic plagioclase) is normally present in excess of 10 per cent, and in some beds exceeds 30 per cent. The feldspars are normally sericitized and kaolinized, but many unaltered grains are seen. Muscovite and biotite are the most common accessory minerals but ilmenite, leucoxene, apatite, amphibole, chlorite, magnetite, and garnet are also present. Except for mudstone chips, lithic fragments are rare.

Iron oxide, especially hematite, is generally present, both as detrital fragments and as a cementing agent coating the surface of most grains. Small amounts of calcite and locally dolomite are present in most beds as interstitial fillings; in places the concentration is sufficient to impart a 'white flecked' appearance to the sandstone. Where the carbonate content is greater than normal, the enclosing rocks are less friable. Manganese oxide also is usually present, occurring as scattered specks and concentrations along bedding or crossbedding planes, and locally in small pods.

Individual sandstone units commonly lens-out or wedge-out in less than 300 feet; locally they are abruptly terminated by scour-fill structures. The thickness of the units varies greatly, but does not normally exceed 10 feet. Internally, these beds usually exhibit crossbedding; the lenticular type is most prominent, but wedge and tabular types also occur. The parallel orientation of large mica flakes along surfaces of lenticular crossbedding gives some weathered and eroded sandstones a 'schistose appearance'. Units exhibiting regular stratification are rare. They probably represent top-set beds.

Mudstone Breccia

Calcareous mudstone breccia, also called conglomeratic limestone (Gesner, 1846), concretionary limestone and calcareous conglomerate (Dawson and Harrington, 1871), brecciated conglomerate (Bain, 1893) and claystone breccia (Frankel, 1966), is locally seen and has widespread exposure in adjacent western and southern parts of the island (Fig. 3). The breccia normally consists of fragments of mudstone and grains of quartz and mica cemented by calcium carbonate and small amounts of iron oxide. Fragments of sandstone are only locally abundant. The shapes and sizes of the lithic particles vary greatly. In most beds they are platy, angular fragments from a fraction of an inch to 3 inches long, but in some areas, cylindrical pebbles of mudstone are prominent.

Figure 3. Wave cut exposure of calcareous mudstone breccia showing imbricate structure, Montagne map-area. (GSC photo 201320)

The breccia beds are lenticular. Their thickness ranges, in general, from 3 inches to about 4 feet and their length seldom exceeds 100 feet. They are concentrated at certain horizons and are also found as isolated lenticles. The breccia beds commonly exhibit parallel orientation of cylinder-shaped particles, imbricate structures, and the characteristics of intraformational breccias. Some of the mudstone fragments were distorted upon compaction and consolidation of the sediment; they are bent around other particles and are irregular in thickness.

The breccia normally is light grey, flecked with red or reddish brown or, red to reddish brown flecked with light grey. Purple sandstone and mudstone fragments are locally prominent. The colour of the breccia apparently depends both on the hue and chroma of the lithic fragments and the ratio of these fragments to the crystalline calcium carbonate cement. Chemical analyses[1] indicate that these beds contain 30 to 77 per cent calcium carbonate and 1 to 3 per cent magnesium carbonate (calculated as maximum carbonate from available carbon dioxide). Carbonate not only constitutes the matrix, but also impregnates the lithic fragments.

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[1] Analyses made by the Geological Survey of Canada and the Experimental Farms Service, Canada Department of Agriculture.

Impressions of plants and hematitic plant replacements are rare in these sediments. A few vertebrate remains have been found in similar beds in Malpeque, Charlottetown, and Montague map-areas (Langston, 1963).

The log of a hole drilled for the provincial government near Spring Valley (see Appendix B for log, and Fig. 2 for location) indicates the character of the breccia and the interbedded sandstones. A similar core from the French River area (French River No. 1; see Howie, 1966) is on file with the Geological Survey of Canada.

Conglomerate and Pebbly Sandstone

Two different conglomerates and their pebbly sandstone facies outcrop in central Prince Edward Island.

In one variety of conglomerate, which is exposed near Springton, Millvale, Mill Cove, and Bedford Station, 69 to 77 per cent of the pebbles are quartzite and 10 to 16 per cent are quartz. Basalt and gneiss pebbles are present in lesser amounts, and granite, granodiorite and rhyolite are uncommon. Sandstone, mudstone breccia and mudstone pebbles, identical with local bedrock are rarely found. Most pebbles are well rounded and are disc-, cylinder-, and egg-shaped.

The conglomerate matrix normally consists of coarse-grained angular to subangular sand grains, poorly cemented by iron oxide and small amounts of carbonate. The resulting conglomerate is generally friable. In places, however, irregular lenticles have been cemented, mainly by carbonate, to nonfriable masses.

The conglomerate normally occurs in tabular and lenticular beds from 1 foot to about 10 feet thick and 150 to 200 feet long. Each exposure usually has several conglomerate beds which exhibit a large range of particle sizes, but each bed has rather good sorting. The conglomerate beds are separated by pebbly and non-pebbly arkose and feldspathic sandstone, ranging from 1 foot to more than 10 feet thick (Fig. 4).

The other conglomerate, which is exposed at Westmorland and Gambles Corner, has matrix, bedding, interbeds, and cementation similar to that described above but it has conspicuous and distinctive pebbles of aphanitic igneous rocks; these are chiefly rhyolites which exhibit flow structures or are porphyritic. These acrilic pebbles constitute 30 to 35 per cent of the lithic fragments. Quartzite comprises 30 to 40 per cent, quartz 20 to 25 per cent, and phaneritic igneous rocks, chiefly granites and granodiorites, less than 10 per cent of the remaining fragments. Mudstone pebbles are locally common, and sandstone pebbles are rare. The shapes of these pebbles are extremely varied. Those with very low sphericity are abundant. Well-rounded particles are uncommon, and most of them are subrounded.

The conglomerate and its pebbly sandstone facies locally incorporate lenses of calcareous mudstone breccia, which commonly contains the diagnostic aphanitic igneous pebbles, and lenses of a purple sandstone and mudstone which are found with the breccia in other locales.

Mudstone

Although mudstone is usually seen only in quarries, along roadsides, and in limited coastal exposures, its widespread distribution is suggested by the character of the clayey till, which locally consists almost exclusively of angular fragments of this lithology.

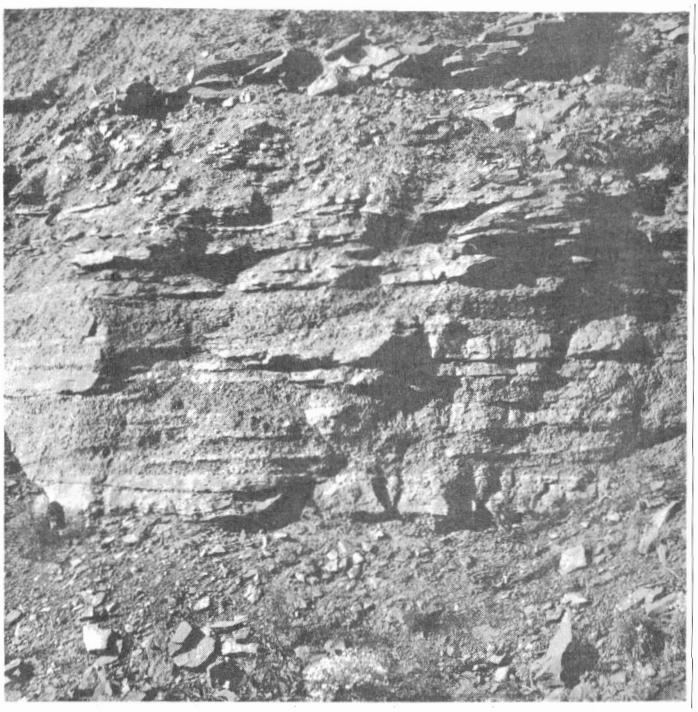

Figure 4. Unit C. Interbedded conglomerate and sandstone at Springton quarry, Rustico map-area. (GSC photo 201321)

Individual beds and lenses of mudstone normally are less than 3 feet thick and 200 feet long. Their colour varies greatly. Most are brown, reddish brown, or red. Purple, greenish grey, grey, and green are rare.

STRATIGRAPHY

In southeastern Prince Edward Island, Frankel (1966) showed that the sequence of sediments overlying the Governor Island sediments is composed of three rock-stratigraphic units. These were designated from oldest to youngest as units A, B and C. Unit A was further divided into three subunits labelled A1 (oldest), A2, and A3[1]. Cursory examination of Rustico map-area and adjacent parts of the island (see Fig. 2) indicated that only some of these rock-stratigraphic units outcrop here, and that in places, other distinctive facies occur. The lithologies, thicknesses, relationships and ages of these units in the southeastern and central parts of the island are shown in Table I.

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[1] The diagnostic characteristics of these units are summarized in Appendix A. For more details see Frankel (1966).

		SOUTHEASTERN PRINCE EDWARD ISLAND			CENTRAL PRINCE EDWARD ISLAND		
		Age	Maximum thickness (in feet)	Lithology	Age	Minimum thickness* (in feet)	Lithology
Unit C		?	225	Mainly sandstones; pebbly sandstones and conglomerates with well-rounded disc-, cylinder-, and egg-shaped pebbles dominantly of quartz and quartzite.	?	50	Same as in southeastern part
Regional (Angular) Unconformity					Unconformity		
Unit B		?	1700	Mainly coarse-grained clastics containing angular and subangular rock and large mineral fragments. Exposures weather rapidly to form a residual mantle of sand and gravel.			
Disconformity							
Unit A	A3	Lower(?) Permian	900	Sandstones (85%) and mudstones (15%). Mudstone breccia restricted to thin mudstone chip concentrations along bedding planes. Mainly light-coloured rocks.	?	350	Same as in southeastern part
	A2	Lower Permian	2000	Sandstones (75%), mudstones (20%) and large lenticles of calcareous mudstone breccia (5%). Mainly intermediate coloured rocks.	Lower Permian	1000	Same as in southeastern part; in places pebbly sandstone, conglomerate and mudstone breccia containing numerous pebbles of aphanitic igneous rocks exhibiting flow structures or phenocrysts.
	A1	Lower Permian	600+	Sandstones (65%), mudstones (30%) and large lenticles of calcareous mudstone breccia (5%). Mainly dark-coloured rocks.	Not seen; could outcrop at Rice Point and may have been penetrated by drilling at Bacon Point.		

* Based on a small number of measured sections; detailed study may show greater thicknesses.

TABLE I. Stratigraphic units in southeastern and central Prince Edward Island

Subunit A3

Over the eastern two-thirds of Rustico map-area, covering the region from Pleasant Grove and Suffolk west to the longitude of Hunter River, bedrock exposures are not common, and except for a few places along the coast and in excavations for fill materials, they are very limited in lateral extent and are only a few feet high. In this region, the outcropping sediments are mostly sandstones which in places exhibit a well developed blocky fracture. Mudstone breccia is rarely seen, and it is limited to thin mudstone-chip concentrations along bedding planes. Fine-grained detrital sediments are not common. Manganese oxide is usually limited to disseminated specks, and the overall colour of the bedrock is lighter than that which is seen along the shore of Hillsborough Bay. These sedimentary rocks, like those exposed just south of the Hillsborough River (Frankel, 1966), appear to be part of subunit A3.

Subunits A3-A2

Close to Orby Head, along the Gulf of St. Lawrence, calcareous mudstone breccia lenticles, like those in subunit A2 in the southeastern part of the island, outcrop in the tidal zone. In the cliffs above them are sandstones and some fine-grained detrital sediments which appear to belong to subunit A3. To the south of Orby Head, in the region encompassing Hunter River, Darlington, North Wiltshire, and Tyrone, fine-grained detrital sediments are seen with much greater frequency than in the more eastern parts of the map-area, and locally, they comprise most of the exposed bedrock.

To the west of this region of abundant mudstone outcrops, mudstone breccia lenticles, identical to those in subunit A2 of southeastern Prince Edward Island (Frankel, 1966), appear in increasing amounts until, in the adjacent parts of Malpeque and Summerside map-areas, they have widespread surface exposure. The sandstones and fine-grained detrital sediments associated with the mudstone breccia are, overall, slightly darker in colour than those exposed in the eastern and central parts of Rustico map-area.

Although the reconnaissance nature of these observations prevents the exact placement of stratigraphic boundaries, it is apparent that west of Orby Head-Hunter River-Tyrone the rock sequence gradually passes through the lower part of subunit A3 into subunit A2. Dawson and Harrington earlier (1871) noted that denudation of strata west of New London was more extensive than to the east.

To the south, in the adjoining Charlottetown map-area (Prest, 1964; Prest and Brady, 1964) a similar situation apparently occurs. Cursory examination of the bedrock south of Eliot River suggests that most of it belongs to subunit A2. North of Eliot River and on into Rustico map-area, rocks similar to those in subunit A3 appear with increasing frequency until they alone are seen.

Close to Westmorland and Gambles Corner, the mudstone breccia of subunit A2 is associated with the conglomerate containing many pebbles of aphanitic igneous rocks which are porphyritic in texture or exhibit flow structure. This association is also seen at Sevenmile Bay, Park Corner, Spring Valley, and Eliot River, where the sandstone and the mudstone breccia locally contain these lithic elements. This pebbly facies of subunit A2 has not been found on the east side of Hillsborough Bay (Frankel, 1966).

Figure 5. Wave eroded outcrop of Unit B conglomerate, Montague map-area. (GSC photo 201319)

In the mudstone breccia at French River in Malpeque map-area, Bathygnathus borealis Leidy was found about 1845, and at close-by Irishtown and Spring Valley, other vertebrate remains were recently discovered in similar rocks by W. Langston and L. Frankel. These fossils indicate that the rocks are early Permian (Wichita-Clear Forks) in age (Romer, in Dunbar et al., 1960; Langston, 1963).

Subunit A1

The sediments of subunit A1 have not been seen in Rustico map-area, or in the examined parts of the surrounding map-areas. However, if structural trends from the northeastern shores of Hillsborough Bay (Frankel, 1966) persist, these sediments could outcrop along Northumberland Strait, in places such as Rice Point. Sediments described by Prest and Brady (1964) in the lower part of cores from Bacon Point area seem to belong to this subunit.

Unit B

The characteristic sharpstone conglomerates and lithic sandstones of unit B (Fig. 5), which overlie subunit A3 in Montague map-area, have not been seen in this part of the island. The possible reasons for their absence will be discussed in another section of this report.

Unit C

Unit C, which is identified by the well rounded, disc-, cylinder-, and egg-shaped, dominantly quartzite and quartz pebbles of its conglomerate facies, outcrops near Mill Cove, Millvale, Hope River, Bedford Station and Springton. A small exposure of pebbly sandstone close to North River may

also belong to this unit. Near Bedford Station and Mill Cove, unit C apparently overlies subunit A3 which is seen in nearby outcrops. In the Springton area, unit C is seen in a narrow belt bounded on the north by one or more faults. The surrounding rocks belong to subunit A3, and beds assignable to subunit A2 outcrop close-by. The situation in these places seemingly is unlike that in the Montague map-area where unit C overlies unit B (Frankel, 1966). It is possible, however, that unit B is under unit C in these areas, but it has not yet been exposed in operating quarries.

The stratigraphic position of the rocks closely surrounding and underlying the conglomerate between Trout River and Hope River are not known.

DEPOSITIONAL ENVIRONMENTS[1]

The materials composing the rocks of unit A apparently were derived from sources on and outside of the island. The mudstone breccias are intraformational, their mudstone fragments being derived from local rocks. This is evidenced mainly by the shapes of the fragments and their lithological identity with exposed beds. The conglomerates and sandstones, and probably the finer clastics also, were derived from extra-basinal sources. This origin is concluded because there are no basement rocks exposed on the island which could have been the source of the conglomerate pebbles, and the older and younger sandstones of this unit appear to have similar texture and maturity, indicating that reworking was not extensive.

The irregular but widespread distribution of the conglomerates and other pebbly sediments of subunit A2, and their intimate association with the extensive claystone breccia, which in other map-areas has yielded the remains of fish, amphibians, and reptiles (Langston, 1963), suggests that they were deposited in stream channels at or close to their confluence with shallow lakes. A stream channel origin for the conglomerates at Gambles Corner and Westmorland was suggested earlier by Milligan (1949).

The greater concentration of conglomerates and other pebbly sediments of subunit A2 in the southern and western parts of the area shown in Figure 2, suggests that their source was southwest of the island. Because of the limited examination of the rocks in this area, it is difficult to evaluate the seeming absence of these pebble-bearing beds east of Hillsborough Bay. The streams that carried them may not have extended across the present area of Hillsborough Bay, or if they did, they may have deposited so few pebbles that they have not been seen in outcrops. Van de Poll's (1966) study of Pennsylvanian paleocurrents in the Moncton Basin indicates a transport direction northeastward towards central Prince Edward Island. If this continued into the Early Permian, it could explain the distribution of these pebbles. It is also possible, as is indicated in a subsequent section, that a fault extends along Hillsborough River, and is responsible for the absence of these sediments.

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[1] Frankel (1966) discussed the depositional environments of the various rock-stratigraphic units in detail. Here, these data will be summarized and additional information pertinent to Rustico map-area, in north-central Prince Edward Island, will be stressed.

Like the sediments of unit A in southeastern Prince Edward Island (Frankel, 1966), those of central Prince Edward Island seem to show the changes that occur as continued alluviation builds up a surface, gradually changing a partly reducing deltaic-lacustrine environment to a better drained, oxidizing floodplain – alluvial fan environment.

The sediments of unit C are also of extra-basinal origin. The maturity of the sandstones, which are essentially the same as in unit A, and the size and composition of the conglomerate pebbles, preclude their being reworked from older sediments on the island. The dominant quartzite-quartz composition and the well-rounded character of the conglomerate pebbles suggests low relief and slow erosion in the source area, resulting in disintegration of the unstable rock types and rounding of the more resistant rock types close to their source.

The occurrence of these conglomerates and pebbly sandstones in narrow, elongated deposits and isolated pods that have no systematic relationship to each other, and their rapid gradation into nonpebbly sandstones, suggests that they were deposited in the meandering and perhaps braided channels of streams whose geographic position changed as the area was aggraded. The streams that carried these pebbles apparently covered most, if not all, of the eastern and central parts of the island.

STRUCTURAL GEOLOGY

This discussion of structural trends in central Prince Edward Island (see Figs. 1 and 2) is based primarily on evidence provided by the areal and topographic distribution of the various rock-stratigraphic units. Dip and strike is only locally used to determine structure because too few observations were made in most areas to assure that true bedding and not the complex crossbedding was measured.

Folds

Outcrops of unit C conglomerate and pebbly sandstone are found along or close to the shore of Gulf of St. Lawrence near North Lake, Bayfield, Deroche Point, Tracadie Cross, and Blooming Point in Souris and Mount Stewart map-areas and also in the relatively low-lying region between Winter Bay and Bedford Station in the easternmost part of Rustico map-area.[1] To the west, subunit A3 is exposed and close to the longitude of Hunter River both subunits A3 and A2 are seen in the topographically higher regions. Along the western boundary of Rustico map-area and on into Summerside map-area subunit A2 comprises the exposed bedrock.

Assuming that these units are correlative with the lithostratigraphic section established in southeastern Prince Edward Island (Frankel, 1966), it is then apparent that the strata increases in age from west to east (see Fig. 2). Older beds in the west and younger beds in the east are at essentially the same topographic elevations. Another salient point is that the western part of the subunit A3 outcrop area apparently is surrounded by subunit

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[1] Concentrations of unit C-type pebbles are seen as beach gravels at a number of places along the north shores of Souris and Mount Stewart map-areas. They apparently come from underwater outcrops.

A2. This is poorly defined in the north, which has been only casually examined, but it is well documented to the south in places such as Bacon Point[1] and along the northeastern and eastern shores of Hillsborough Bay (Frankel, 1966).

These cursory observations strongly suggest that the major structure occupying this part of the island is an eastward-plunging syncline. The exact position of the axis of this structure in Rustico map-area is not known, but it seems to parallel those of Gallows Point anticline and Kilmuir syncline of southeastern Prince Edward Island (Frankel, 1966). East of Rustico map-area, the axis apparently lies in the Gulf of St. Lawrence, close to the north shore of Mount Stewart and Souris map-areas where unit C conglomerate outcrops and shore gravels containing pebbles of this conglomerate are seen. In these areas, it could represent the synclinal axis placed in a slightly more southerly position by Milligan (1949) who recorded northerly dips for the area between Souris and East Point.

To date, there has been no comprehensive study of rock types and their distribution in Mount Stewart and Souris map-areas. However, primarily on the basis of an airphoto study of stream courses and ridge and cuesta development, Crowl (in press) has concluded that the major structure is a homocline whose beds strike approximately 120 degrees and dip northeast at a low angle. If the synclinal axis of Rustico map-area continues northeastward along the shores of the Mount Stewart-Souris Peninsula and if Crowl's interpretation of the structure is correct, there probably is an unconformable contact between the rocks of unit C and those of the homocline. This is suggested not only by the distribution of unit C conglomerate outcrops, but also by the drainage pattern developed on these beds which diverges from that which is developed away from the north shore. The unconformable relationship between unit C and the older beds has been demonstrated in southeastern Prince Edward Island (Frankel, 1966).

In view of Milligan's (1949) and Crowl's (in press) observations, it seems unlikely that the anticlinal axis shown by Roliff (1962) exists on Souris Peninsula.

No evidence has been found in Rustico map-area for the anticlinal axis depicted by Ells (1902) as extending from Cape Tormentine, New Brunswick across Northumberland Strait to Tryon, and thence north to Rustico. The New Brunswick part of this structure, called the Westmorland anticline (Gussow, 1953) is pictured by Williams (1967) as terminating along the south shore of Prince Edward Island.

In the eastern half of Malpeque map-area, close to Cape Tryon, the attitudes of the beds of subunit A2 suggest the presence of an anticlinal structure.[2] Ells (1902) noted this trend, and considered it to be part of the Bedeque Bay anticlinal axis which he extended from close to Cape Bald, New Brunswick across Northumberland Strait, through Summerside, and thence north to the vicinity of Cousins Pond, approximately 2 miles west of Cape Tryon. However, in view of Gussow's (1953) study of the New Brunswick

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[1] Prest (1964) and Prest and Brady (1964) described the rocks in this area but did not assign them to a rock-stratigraphic unit.

[2] The presence of a fold in the Cape Tryon area was first recognized by Dawson and Harrington (1871).

area, such an extension from the mainland seems unlikely. Therefore, excluding this possibility, the poorly defined structure could be a local minor fold (as is shown by Roliff, 1962) of which there seem to be many on the island, or part of a larger structure which has not yet been delineated.

Of great interest, in connection with this structure, is the area on the west side of Malpeque Bay. Here, at MacDougall, Pennsylvanian (Stephanian) spores were found in well cuttings close to the surface and at depth. Also at close-by Wellington Station and Port Hill, similar spore assemblages were found approximately 1,700 feet below sea level (Barss, et al., 1963). The structure of the area is depicted as an uplift having normal faults along its southeastern flank (Roliff, 1962). Williams (1967) shows the uplift trending northeast, and he, like Roliff (1962), places the Port Hill borehole within the uplift, and the Wellington Station and MacDougall boreholes on its eastern flank.

One could speculate, however, that the configuration of the area is somewhat different. If the basic structure of central Prince Edward Island is a continuation of that in the southeastern region, as cursory field work suggests, then the fundamental pattern is a series of broad parallel or semi-parallel folds plunging northeast. The axis of such a fold projected west from the Cape Tryon region would pass through the area of the MacDougall-Wellington Station boreholes. Along this line, Pennsylvanian (Stephanian) rocks occur in the west (Barss, et al., 1963) and early Permian beds in the east (Romer, in Dunbar, et al., 1960; Langston, 1963), suggesting an eastward plunging anticline. In this interpretation, the Port Hill high is the result of uplift along a fault plane(s) which cross the axial trend of a larger fold. To account for the absence of Lower Mississippian and the thinness of Upper Mississippian strata in the Port Hill borehole, Williams (1967) postulated movement both before and after Mississippian time. Here, movements during and after Early Permian time are also envisioned.

It is interesting to note that in his map of Pennsylvanian time, Roliff (1962) depicts the Cape Tryon anticline and also two parallel anticlines in the MacDougall-Wellington Station area, but seemingly considers them to be isolated structures and not part of a single large fold crossing this part of the island.

Faults

In the west half of Rustico map-area, faults were seen at Springton, Brookvale, and near Emyvale. Drag folds, with some minor displacement of strata, were seen along the road north from Stanchel.

At Brookvale, Springton, and south of Emyvale, the trends of the faults are approximately 120 degrees. This orientation is also seen in the drag folds and beds with minor displacement along the road north from Stanchel. In the other localities, the trends of the faults could not be determined.

All faults appear to be normal. The Springton gravel pits are in a graben-like structure. Younger unit C conglomerate is down-faulted into subunit A3 which outcrops in the area to the north and south of the conglomerate-bearing beds. At Brookvale, and both north and south of Emyvale, the northern blocks have moved down relative to the southern blocks.

In the road metal quarries at Brookvale and Springton, fault zones are present; contorted beds with small faults are visible in the excavated parts of the downthrown blocks for approximately 50 feet from the major fault plane surfaces. In the largest of the Springton quarries, most of the conglomerate-bearing beds have been removed, exposing the major fault plane over the entire width of the north wall. In places, however, small pieces of conglomerate still adhere to the gouge. The surfaces of the conglomerate pebbles facing the fault are highly polished and they bear parallel scratches whose orientations indicate only vertical movement at this locality.[1] Similarly, the orientation of slickensides along the major fault plane at Brookvale, also indicates only a vertical movement component. The vertical displacement along these faults is not known.

Because of the concentration of faults, and the essentially uniform orientation of the fault trends in the area between Springton and Brookvale, it appears that they are not isolated occurrences, but instead outline a complex graben or tilt (rotation) block zone. Some of the fault outcrops, such as those at Brookvale and south of Emyvale, may be along the same trace, but more study of the area is required to ascertain this.

Another indication that the individual faults may continue for long distances beyond the places where they are seen in outcrop, is the rectangular to subrectangular drainage pattern in some areas. Such a pattern is developed just west of New Wiltshire, where a tributary to the southward-flowing Eliot River flows east-southeast along what could be the trace of the fault at Springton. A similar situation occurs in the streams close to Brookvale.

Another fault system, trending 130 degrees is suggested by the courses of Trout River and an unnamed tributary to Hunter River Pond. Across this trend, there are relatively abrupt topographic changes and lithologic differences. Except for a small area close to St. Ann, the elevations in the highlands northeast of these water courses are below 300 feet; to the southwest, however, large areas are above 300 feet, and in many places elevations exceed 400 feet. These topographic changes could result from lithologic differences in an orderly sequence of folded rocks, but because all known outcrops of unit C conglomerate in this area are northeast of Trout River, away from the axis of the syncline which appears to cross the map-area, their location seems best explained by faulting.

Hillsborough River, in the eastern part of Rustico map-area, is thought by some investigators to mark a pre-Permian fault line e.g. the post-Windsor-pre-Pennsylvanian faulting of Roliff (1962) and the Harvey-Hopewell fault of Webb (1968). There are lithologic differences along Hillsborough River that also suggest post-Lower Permian movement; the writers' investigations show that outcrops of unit B are restricted to the areas east of the river, and that the conglomerate facies of subunit A2 does not cross Hillsborough Bay.

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[1] No fault was seen in the easternmost Springton quarry; however the presence of many polished pebbles bearing parallel scratches in the excavated and piled rubble suggests a hidden fault.

Along the Gulf of St. Lawrence in Malpeque map-area, a fault is found east of French River and drag folds close to Cape Aylesbury. In Spring Valley region, numerous calcite-filled fractures in the claystone breccia suggest a local disturbance. These may all be related to salt movement (Roliff, 1962).

DEPOSITIONAL AND TECTONIC HISTORY

Prince Edward Island apparently was part of a subsiding basin in which thick sediments, eroded from surrounding highlands, were deposited in Permo-Carboniferous and perhaps later times. The oldest exposed sediments are of Pennsylvanian (Pictou) age. They are found close to Miminegash, at MacDougall, and on Governor Island. The thickest section is seen in the southeastern part of the island. Here, approximately 3,500 feet of Early Permian (unit A) rocks are visible. Above them lie about 2,000 feet of younger sediments (units B and C) whose age(s) is not yet known (Frankel, 1966).

In Rustico map-area only the rocks of subunits A2, A3, and unit C are exposed. The sediments of unit B, which occur in all the eastern map-areas, have not been seen west of Hillsborough River, and there is yet no evidence to suggest that they were ever present in the central or western parts of the island. However, because of the proximity of unit B outcrops to the easternmost part of Rustico map-area, it is possible that these sediments were deposited here. Important in this respect, is the postulated fault along Hillsborough River. If movement along this line occurred not only in pre-Permian time (Roliff, 1962; Webb, 1968) but also after the deposition of unit B, erosion after faulting could account for the stratigraphic differences east and west of the river. Unit C was deposited by meandering and perhaps braided streams and the scattered, but widespread, distribution of the conglomerate facies of this unit suggests that it was emplaced across most, if not all, of the eastern and central parts of the island. Remnants of this unit seem to be preserved only in the axial, down-plunge parts of synclines and in downfaulted areas.

The tectonic history of Prince Edward Island remains obscure, in part because there is little subsurface data available, particularly on the distribution of salt deposits. To date, only the Gallows Point anticline is known to have a salt 'core', but other evaporite deposits have been encountered in drilling (see Roliff, 1962) and this leads some investigators to speculate that the island's structure is primarily the result of salt movements. Assuming that future studies will reveal more salt, the basic question to be answered is whether the folds are kinetic structures – being essentially gravity phenomena, or tectonic structures – those primarily produced by compressive forces. To determine this would require a comprehensive seismic survey followed by extensive drilling. Although in part speculative, field data indicate that there is a series of broad, semiparallel folds with common eastward plunge extending from Wood Island west to Cape Tryon. This supports the idea that the folds are primarily tectonic features, but it does not negate the possibility of the modification of their form (e.g., domal shape of Gallows Point anticline) by the subsequent migration and gravity rise of salt ('halokinesis' of Trusheim, 1960).

The interpretation of the apparent unconformable relations of units B and C, and the cause of the faulting in post-unit C time also depends on more knowledge of possible salt movements. Frankel (1966) postulated that two periods of tectonic activity were evidenced by the surface rocks of the island. The first occurred after the deposition of unit B, and it is thought to reflect more intense tectonic activity on the mainland. The later folding, evidenced by the unconformable relationship of unit C and the older rocks, is of lesser magnitude than the first, but it follows the previously established trend. The preservation of unit C outliers in downdropped areas, indicates that major faulting occurred concurrent with or following the second episode of folding. This second period of folding and the closely related faulting could be a reflection of salt movement and the subsequent crustal adjustments and not the result of regional tectonic activity.

The present erosional topography of the island is apparently controlled by the structural trends. Inverted relief (Lobeck, 1939) is prominent; up-plunge portions of the synclines comprise most of the high ground.

ECONOMIC GEOLOGY

The conglomerate deposits provide high quality materials for road construction and concrete aggregate. In places, the friable sandstone also is excavated and used for construction fill.

Although beds and lenticles of calcareous claystone breccia, which contain from 30 to 76 per cent calcium carbonate and 1 to 3 per cent magnesium carbonate (calculated as maximum carbonate from available carbon dioxide), are widespread in the map-area, they are too thin and too limited in extent to be of value as a source for agricultural lime.

Preliminary study of the bedrock configuration indicates the presence of broad folds and faults which could form structural traps for petroleum and gas accumulation.

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APPENDICES

APPENDIX A

DIAGNOSTIC CHARACTERISTICS OF THE ROCK-STRATIGRAPHIC UNITS

UNIT A

The distinctive sediment is calcareous mudstone breccia which only rarely occurs in the younger units. On the basis of slight differences in the character of the breccia and the associated sandstones and mudstones, the unit can be divided into three subunits. Vertebrate fossils and spores indicate that the age of this unit is Lower Permian (Langston, 1963; Barss, et al., 1963). The sediments show the changes that occur as continued alluviation builds up a surface, changing a deltaic-lacustrine environment to a flood-plain - alluvial-fan environment.

Subunit A1

Type locality is at Gallows Point on the northwestern shores of Orwell Bay. Calcareous mudstone breccia is common, and it contains abundant purple, purplish red, and other dark-coloured mudstone fragments. Plant impressions and hematitic plant replacements are common in the breccias and sandstones. Sandstones and mudstones are highly varied in colour and, in general, are darker than those in the younger subunits. Manganese oxide pods and concentrations along bedding planes are very abundant.

Subunit A2

Type locality in the shore of Pownal Bay, about a mile northwest of Cherry Valley and a quarter mile southeast of the old wharf. Calcareous mudstone breccia is common, and it contains many rock fragments lighter in colour than those in the A1 breccia; purple and purplish red fragments are not common. Plant impressions and hematitic plant replacements are rare in the breccias and sandstones. Bone fragments are rare but they are more common here than in the other subunits. The sandstones and mudstones generally are lighter coloured than those in the older subunit, and manganese oxide concentrations are not as prominent. Conglomerate and pebbly sandstone facies are found only in the central part of the island.

Subunit A3

Type locality is along the Eldon wharf shore (southeastern shore of Orwell Bay). Calcareous mudstone breccia normally does not exceed 3 inches in thickness, and it mainly occurs as mudstone-chip and calcium carbonate concentrations along bedding planes. Large lenticles have not been seen. No plant impressions or hematitic plant replacements were found in this breccia. The sandstones and fine-grained detrital sediments are, overall, lighter in

Subunit A3 (cont'd)

colour than those in the older subunits. Manganese oxide is normally limited to disseminated specks; pods are rare. The sandstones have a blocky fracture, which is better developed than that in the older subunits. Although not common, current ripple-marks, trails, root marks, and mud-cracks are more abundant in this subunit than in subunits A1 and A2. Plant impressions are locally seen in the sandstones and mudstones.

UNIT B

Type locality is at Wood Islands. It is an alluvial fan deposit. The diagnostic sediments are coarse-grained clastics containing many angular and subangular rock fragments. Prominent lithic particles include quartzite, gneiss, schist, slate, phyllite, granite, granodiorite, rhyolite, and basalt. Large mineral grains, such as vein quartz, feldspar, amphibole, and mica, are also common. No single rock type or large mineral fragment predominates. Exposures of these rocks undergo rapid disintegration to form a residual mantle of sand and gravel. Rocks of this unit have not been seen in central Prince Edward Island.

UNIT C

Type locality is the Iona district of east-central Prince Edward Island. It is an alluvial plain deposit, formed by anastomosing and perhaps braided streams. The characteristic rocks are conglomerates and conglomeratic sandstones containing well-rounded disc-, cylinder-, and egg-shaped pebbles which are dominantly quartzite and quartz in composition. Basalt and gneiss pebbles occur in lesser amounts, and rhyolite, granite and granodiorite are rare.

APPENDIX B

ABRIDGED LOG
SPRING VALLEY DRILLHOLE

Drilling Company:	Federal Department of Public Works
Location:	Property of F. Profitt, Spring Valley; Latitude 46°29'55"; Longitude 63°36'40"
Elevation:	Approximately 125'; Total Depth 155.5'
Spudded:	August 4, 1961; Completed August 11, 1961
Rig Type:	D.D. AX Core
Samples examined by:	L. Frankel

Section Cored (in feet)	Lithology
0.0 – 7.2	Calcareous claystone breccia[1]; 44.2 per cent $CaCO_3$[2]
7.2 – 17.9	Sandstone[3]; fine- to coarse-grained; slightly calcareous; with some grey to grey-green reduced zones; a few claystone partings
17.9 – 21.4	Calcareous claystone breccia with a few thin sandstone partings; 44.5 per cent $CaCO_3$
21.4 – 22.3	Sandstone; medium- to coarse-grained; slightly calcareous; with some claystone fragments
22.3 – 23.5	Calcareous claystone breccia; 45 per cent $CaCO_3$
23.5 – 27.4	Sandstone; medium- to coarse-grained; slightly calcareous; a few green reduced zones; some claystone fragments
27.4 – 36.6	Calcareous claystone breccia; 32.2 per cent $CaCO_3$

[1] Colour (dry) usually is light grey, flecked with reddish brown. However, within these beds there commonly are zones that are red to reddish brown, flecked with light grey

[2] Calculated as maximum carbonate from available carbon dioxide. Analyses by Experimental Farms Service, Canada Department of Agriculture

[3] Sandstone colour (dry) ranges from reddish brown to brownish red and commonly shows a gradation within the same unit. In places, carbonate concentration is sufficient to impart a 'white flecked' appearance. All are micaceous, and each can be classified as either arkose or feldspathic sandstone as defined by F.J. Pettijohn (1957): Sedimentary Rocks, 2nd. ed., pp. 283-339, New York, Harper and Bros.

Section Cored (in feet)	Lithology
36.6 - 46.6	Sandstone; medium- to coarse-grained; calcareous and 'white flecked' in places; a few claystone partings
46.6 - 48.6	Sandstone; medium- to coarse-grained; slightly calcareous; with thin calcareous claystone breccia partings
48.6 - 52.6	Calcareous claystone breccia; 36.9 per cent $CaCO_3$
52.6 - 55.2	Sandstone; medium- to coarse-grained; calcareous and 'white flecked' in places; a few claystone partings.
55.2 - 59.0	Calcareous claystone breccia; 47.7 per cent $CaCO_3$
59.0 - 82.0	Sandstone; fine- to medium-grained; slightly calcareous in places; with thin beds of calcareous claystone breccia one foot or less thick
82.0 - 97.4	Calcareous claystone breccia, 1.3 feet to 2.2 feet thick, separated by thin beds of medium- to coarse-grained calcareous sandstone; 40.4 per cent - 43.5 per cent $CaCO_3$
97.4 - 101.4	Calcareous claystone breccia; 47.6 per cent $CaCO_3$
101.4 - 107.5	Sandstone; medium- to coarse-grained; slightly calcareous in places; with thin beds of calcareous claystone breccia
107.5 - 108.7	Calcareous claystone breccia; 41.8 per cent $CaCO_3$
108.7 - 135.3	Sandstone; medium- to coarse-grained; slightly calcareous in places; some claystone fragments
135.3 - 139.6	Calcareous claystone breccia; 35.0 per cent $CaCO_3$
139.6 - 155.5	Sandstone; medium- to coarse-grained; calcareous and 'white flecked' in places

End of hole