COMMONWEALTH OF AUSTRALIA

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DEPARTMENT OF NATIONAL DEVELOPMENT

# BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS

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**RECORDS:**

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Record 1966/145

# PETROLOGY OF SOME CARBONATES IN THE GEORGINA BASIN

by

R.A.H. Nichols



15928/65

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SUMMARY

Carbonate rocks up to 6,000 feet thick, form the major part of the succession in the Georgina Basin, an area of approximately 110,000 square miles in the north-eastern part of the Northern Territory and western part of Queensland, Australia.

Dolomites predominate and form a major unit in the northern, central and southern parts of the basin, while limestones crop out in some marginal areas. Units of quartz sandstone and siltstone are relatively minor.

The different types of carbonates are here considered to range from Lower Cambrian to Lower Ordovician in age; the dolomites are predominantly inorganic, while the limestones are a mixture of organic and inorganic. As fossils are rare in the dolomite units and zones cannot be established, the changes in environment are described from arbitrary intervals of lower, middle and upper parts of the succession.

The types of carbonates are defined, their modes of origin and diagenesis discussed, and the types of environment postulated.

The varieties of limestones and dolomites are microcrystalline (mud), algal, algal-stromatolite, bioclastic, pelletal, oolitic, composite-grain and intraformational breccia.

They contain trace amounts of Co, Ni, Pb, Zn, V, P, and Sr, which vary with the amounts of clay minerals, dolomite, quartz and feldspar silt and sand, and decrease with distance away from an ancient shore-line in the west. Plots of the vertical distribution of the elements in three core-holes indicate that trace elements have some potential for correlating sections of unfossiliferous dolomite.

The dolomites and limestones were also analysed for clay minerals: smectites, mixed-layer clays (smectite-chlorite, smectite-illite), chlorite, illite/mica and kaolin. The variations in abundance and distribution are plotted against lithology logs, and seem to reflect the character of the source material rather than the depositional environment. They have only limited value as correlation parameters.

Carbonates were generally the first deposits to accumulate in the Georgina Basin. Their age is not everywhere established, but Lower Cambrian units here considered part of the basin, occur in the south-western part of the region where deposition was continuous from Precambrian to Cambrian times.

The eroded Precambrian land surface gradually submerged and carbonate sediments overstepped onto the Precambrian surface; environments were generally of low energy in which carbonate muds and rare lime sands accumulated.

Subsidence continued and a vast carbonate province was established by Middle Cambrian times when the region became predominantly a complex of carbonate mud banks, oolitic, pelletal and composite-grain sands, bioclastic sands and rudites, with some quartz sand, each controlled by slight differences in salinity, temperature and current activity. These areas and environments changed vertically and laterally, and some deposits were possibly above sea level periodically, when cementation, dolomitisation and erosion occurred.

Similar environments are known to have persisted in the central part and developed in the southern parts of the region in Upper Cambrian times, and a complex of oolitic, pelletal and intraclastic sands accumulated, alternating vertically and laterally with carbonate mud and algal-stromatolites. These overlie quartzose and bioclastic carbonate muds in the south and denote a change to a more chemical, and possibly higher energy environment.

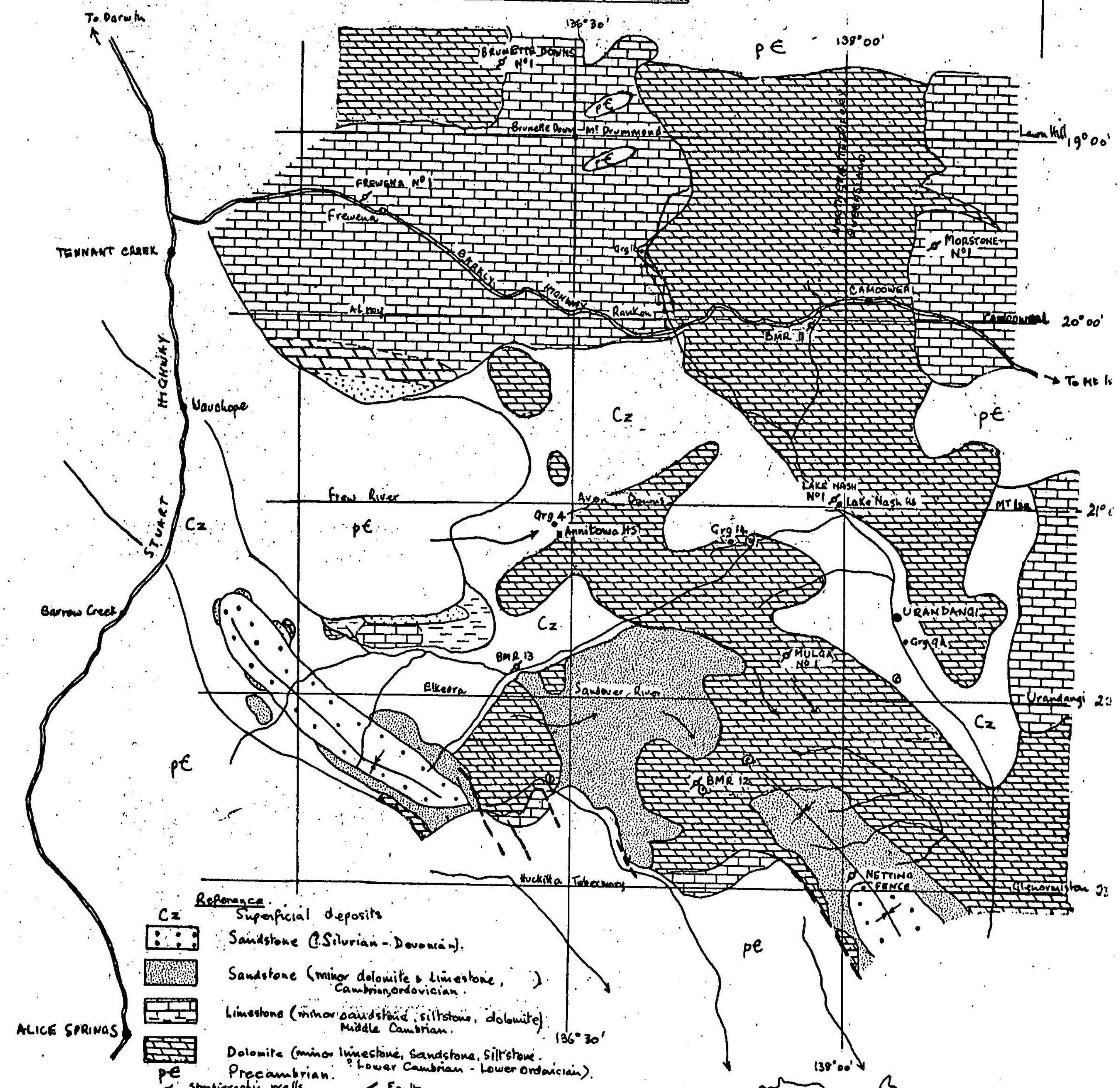
It is assumed that they formed in very shallow water, as intraformational breccias and thin, ripple marked quartz sands accumulated periodically. Other evidence of discontinuities is rare, but superficially similar dolomites and algal stromatolites are forming in intertidal areas at present.

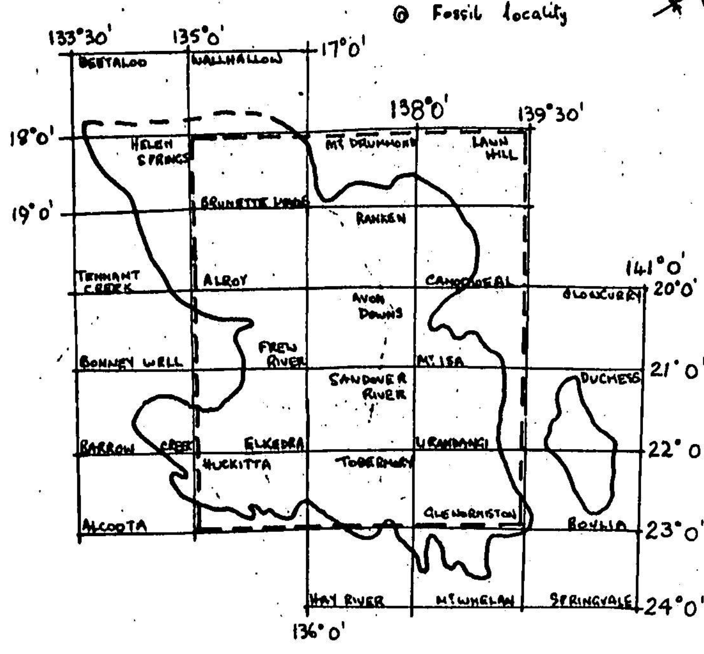
Thus, it is assumed that many parts of the region were periodically above sea level. During these periods cementation and dolomitisation occurred preserving many of the textures and affecting the area on a regional scale.

The carbonate province became restricted in the south-eastern part of the Georgina Basin in late Upper Cambrian and Lower Ordovician times, and quartz sands were deposited adjacent to oolitic and pelletal lime sands.

GENERALISED GEOLOGICAL SETTING OF CARBONATE UNITS

IN THE CENTRAL GEORGINA BASIN (After Milligan, 1963)



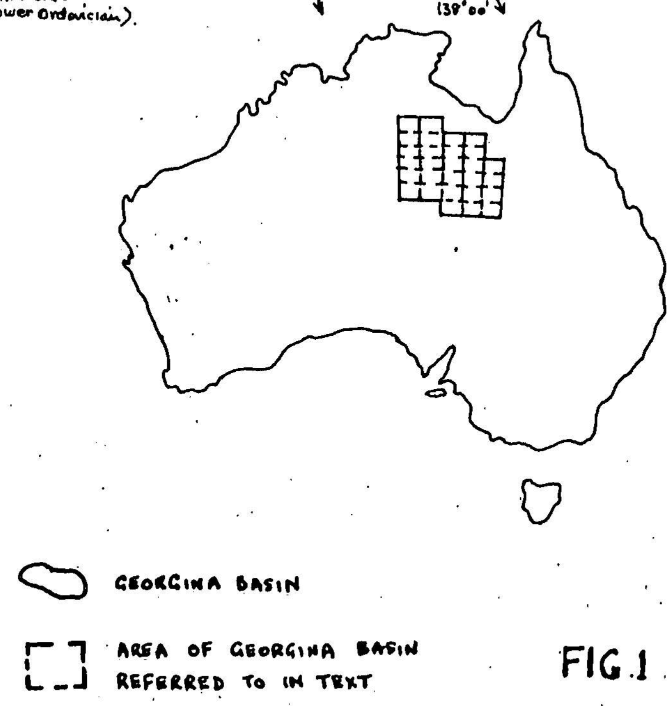




FIG. 1

To accompany Record 1966/145.

# PETROLOGY OF SOME CARBONATES IN THE GEORGINA BASIN

## INTRODUCTION

### General

This report presents the petrology of some carbonate rock units in the Georgina Basin, determined from studies of thin sections, sliced cores and well cuttings. The petrology of the different carbonate rock units is compared, and an attempt is made to reconstruct the carbonate environment of the major part of the basin.

The Georgina Basin is situated in the eastern half of the Northern Territory and the western part of Queensland, and, in the area studied, contains from 1,000 to 6,000 feet of interbedded limestone, dolomite, sandstone and minor siltstone (fig. 1) which, except for two synclines in the southern part, are flat lying or dip gently. These units are here considered to range in age from Lower Cambrian to Devonian, with most of the carbonates ranging from Lower Cambrian to Lower Ordovician in age.

The region was mapped on scales of 1:46,000 and 1:50,000 by officers of the Bureau of Mineral Resources mainly between 1956 and 1965. The Bureau of Mineral Resources also conducted drilling programmes between 1962 and 1964, consisting of 18 shallow core holes in 1962, and three deep stratigraphic wells in 1963 and 1964. Eight Company exploration wells were drilled between 1962 and 1965. Reports concerning the mapping and drilling will be referred to in the text, while the units drilled by the Companies and the Bureau of Mineral Resources are broadly presented in a fence diagram (fig. 2).

Carbonate outcrops are generally discontinuous in the Georgina Basin, and exposures are small in the northern half of the region (Barkly Tableland) where it is largely grassland and outcrop is very scarce; boulders, slabs and rubble predominate. In the southern half, however, in semi desert, the carbonates crop out in low hills, mesas and pavements, with scree and talus occurring on the slopes and flats. Descriptions of the physiography and access are available in the Bureau of Mineral Resources' records and reports, referred to in the text.

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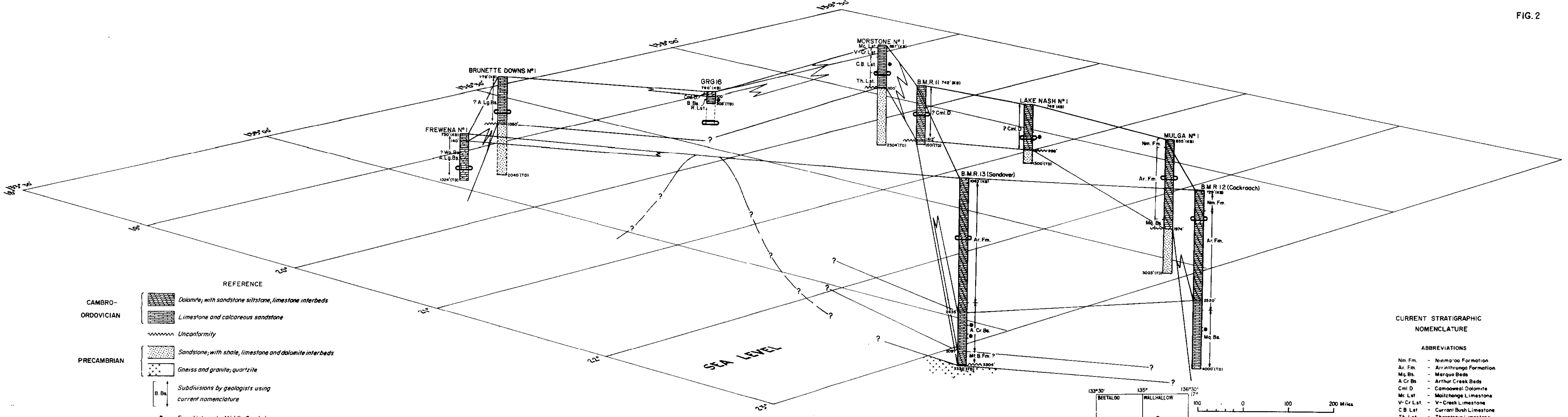
FIG. 2




REFERENCE

CAMBRO-ORDOVICIAN
- Dolomite; with sandstone siltstone, limestone interbeds
- Limestone and calcareous sandstone

Unconformity

PRECAMBRIAN
- Sandstone; with shale, limestone and dolomite interbeds
- Gneiss and granite; quartzite

B. Bs. Subdivisions by geologists using current nomenclature

Fossil interval – Middle Cambrian

729' (KB) Height of kelly bushing above sea level

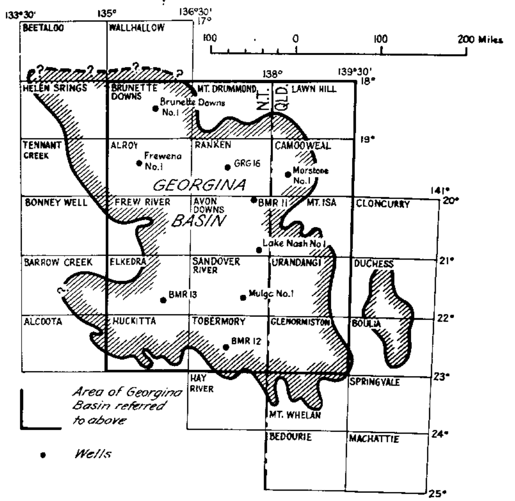
2520' Drilled depth below K B

4000' (TD) Total depth below K B

Indicates where borehole passes through reference plane (sea level)

# DISTRIBUTION OF CAMBRO-ORDOVICIAN CARBONATE FORMATIONS AND ? PRECAMBRIAN BASEMENT IN THE GEORGINA BASIN

(LOOKING NORTH 42° EAST)




CURRENT STRATIGRAPHIC NOMENCLATURE

ABBREVIATIONS

| | | |
|---|---|---|
| Nm. Fm. | - | Ninmaroo Formation |
| Ar. Fm. | - | Arrinthrunga Formation |
| Mq. Bs. | - | Marqua Beds |
| A. Cr. Bs | - | Arthur Creek Beds |
| Cml D | - | Camooweal Dolomite |
| Mc Lst. | - | Mailchenga Limestone |
| V-Cr. Lst. | - | V-Creek Limestone |
| C B Lst | - | Currant Bush Limestone |
| Th Lst | - | Thorntonia Limestone |
| B Bs | - | Burton Beds |
| R. Lst. | - | Ranken Limestone |
| A. Lg. Bs. | - | Anthony Lagoon Beds |
| Wo. Bs. | - | Wonarah Beds |
| Mt B. Fm. | - | Mount Baldwin Formation |

M.N.-G.M.

To accompany Record 1966/145

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Techniques used for Studying the Carbonates.

Apart from thin section studies of carbonates from some outcrops, cores from Bureau of Mineral Resources' core-holes were examined in the following manner. Narrow, continuous strips along the cores were plained and polished with carborundum. This method provides clean surfaces for initial observation.

The cores were then washed and examined in the wet state with hand lens, hydrochloric acid and a steel needle. Intervals of macroscopically, uniform lithologies were measured; representative samples (1 inch to 8 inches long) were chosen from each lithology and from thin interbeds when considered significant. The cores were sawn in half lengthwise and one surface was ground and polished. The other half was used for thin section preparation, and insoluble and calcilog powders.

The core samples were mounted horizontally in plasticene on glass plates; the surfaces were etched with dilute hydrochloric acid and varying degrees of effervescence were noted.

The surfaces were washed and then covered with a solution of Alizarin red S; calcite turned red, pure dolomite remained unstained and ferroan dolomite turned purple (Warne, 1962, p. 35). They were not treated with a mixture of hydrochloric acid and potassium ferricyanide as the Alizarin red S stains indicated the presence of ferroan dolomite.

Thin sections were made from signigicant lithologies and were preferred to peels, as maximum clarity and optical properties were required for mineral and fossil recognition.

All lithologies were subjected to calcimetry. In order to obtain the ratio of limestone to total carbonate for each lithology, thin slices of core perpendicular to bedding, were crushed to a consistent grain size of 0.012 to 0.024 inches. The rock powder was dissolved in cold hydrochloric acid, (10%) and the amount of carbon dioxide lost after one and nine minutes gave an approximation to the actual ratio of limestone to total carbonate.

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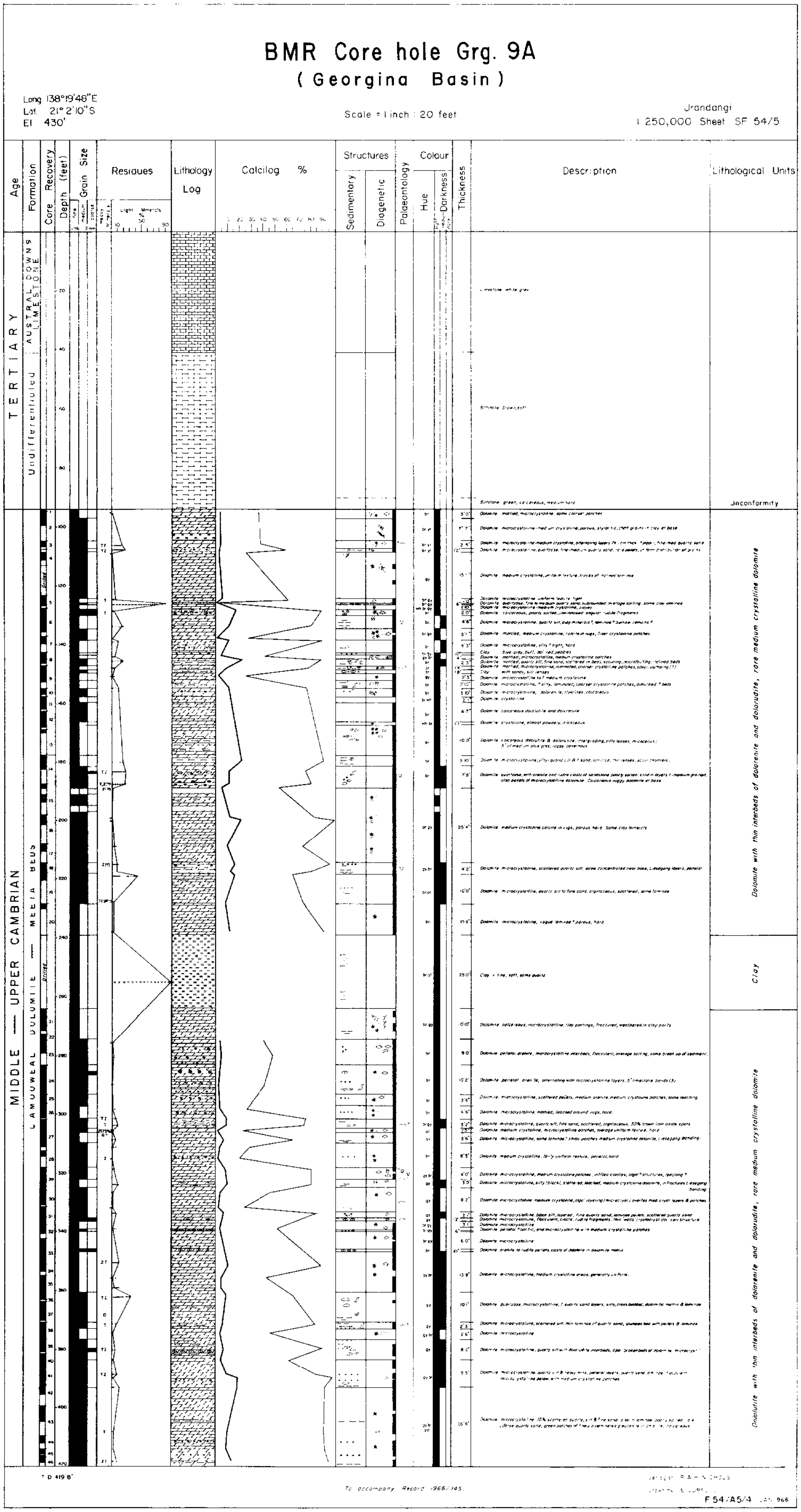
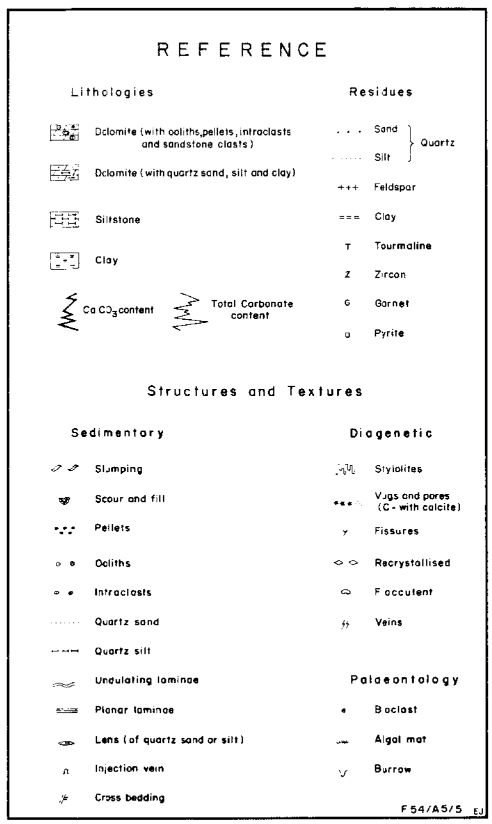
FIG. 3.


BMR Core hole Grg. 9A
( Georgina Basin )
Long 138°19'48"E
Lat. 21°2'10"S
El 430'
Scale = 1 inch : 20 feet
Urandangi
1:250,000 Sheet SF 54/5
Age
Formation
Core Recovery
Depth (feet)
Grain Size
Residues
Lithology Log
Calcilog %
Structures
Sedimentary
Diagenetic
Palaeontology
Colour
Hue
Darkness
Thickness
Description
Lithological Units
TERTIARY
AUSTRAL DOWNS LIMESTONE
Undifferentiated
Unconformity
MIDDLE — UPPER CAMBRIAN
CAMOOWEAL DOLOMITE — MEETA BEDS
Dolomite with thin interbeds of dolorenite and dolorudite, rare medium crystalline dolomite
Clay
T.D. 419'8"
To accompany Record 1966/145.
F 54/A5/4


REFERENCE
Lithologies
Dolomite (with ooliths, pellets, intraclasts and sandstone clasts)
Dolomite (with quartz sand, silt and clay)
Siltstone
Clay
CaCO3 content
Total Carbonate content
Residues
Sand
Silt
Quartz
Feldspar
Clay
Tourmaline
Zircon
Garnet
Pyrite
Structures and Textures
Sedimentary
Slumping
Scour and fill
Pellets
Ooliths
Intraclasts
Quartz sand
Quartz silt
Undulating laminae
Planar laminae
Lens (of quartz sand or silt)
Injection vein
Cross bedding
Diagenetic
Stylolites
Vugs and pores (C - with calcite)
Fissures
Recrystallised
Flocculent
Veins
Palaeontology
Bioclast
Algal mat
Burrow
F54/A5/5

The residues, obtained from dissolving one gram of the remaining powder in warm hydrochloric acid, were dried, and their quantity and mineralogical composition were determined under a binocular polarizing microscope.

Large scale pictorial graphic logs were prepared using the logs of Bouma (1962), as a basis. The pictorial method was preferred to avoid continual reference to the explanation at the top of the log (fig. 3).

Previous Petrographic Investigations.

Brown (1962) and Randal and Brown (1962 a & b) presented detailed petrographic work on the carbonate rocks in the north and north-eastern part of the Georgina Basin, and determined and illustrated the lateral changes in environment during the deposition of the Camooweal Dolomite, Age Creek Formation, Mailchange Limestone and V-Creek Limestone.

Nichols (1963) continued this type of study in the Brunette Downs area to the north-west and the petrology of the Anthony Lagoon Beds was illustrated and compared with that of the Camooweal Dolomite and Age Creek Formation.

Milligan (1963) presented the results of the 18 hole core drilling programme in the Georgina Basin and provided a major step forward by his descriptions of the rock units in a large area of the Basin, and for the first time, the text figures showed the extent of the carbonates and other rocks as units in the Georgina Basin.

In 1963, the Institut Francais du Petrole combined with the Bureau of Mineral Resources in a detailed petrographic study of core-hole Grg 4 in the western part of the Basin (Fehr and Nichols, 1963) attempting to establish a type section through the dolomite and presenting the distribution of many sedimentary and diagenetic structures and textures.

In 1964, a similar graphic log was constructed for the dolomite sequence in core-hole Grg 14 (Nichols and Fehr, 1964), 65 miles further east.

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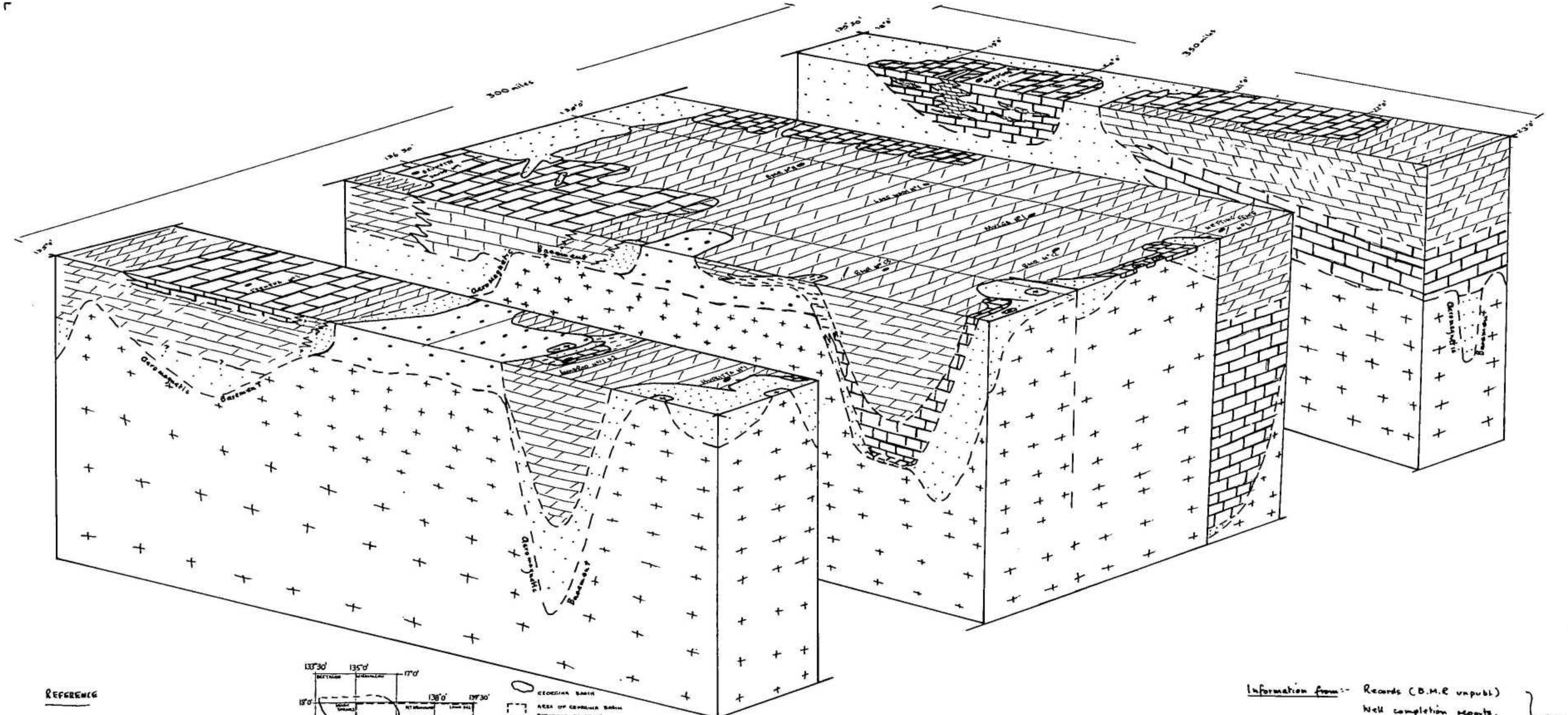
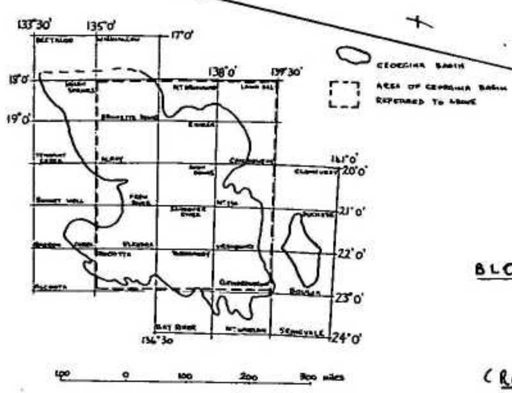



REFERENCE

- Dolomite (minor limestone, sandstone, siltstone ? Lower Cambrian - Lower Ordovician)
- Limestone (minor dolomite, sandstone, siltstone) Middle Cambrian - Upper Cambrian
- Sandstone (greywacke, siltstone, dolomite Upper Proterozoic - Lower Cambrian)
- Quartzite (siltstone, greywacke, volcanics Lower Proterozoic)
- Gneiss Granite (Archean, Proterozoic,
- Stratigraphic wells.




BLOCK DIAGRAM OF GEORGINA BASIN SHOWING RELATIONSHIPS OF MAJOR CARBONATE UNITS

(above non-prospective and aeromagnetic basement).

(Reference plane - general ground level, approx. 750' above MSL).

Information from:- Records (B.M.R unpubl) Well completion reports. Map of magnetic basement contours } see text.

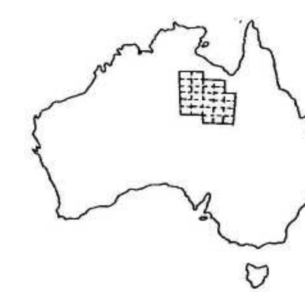


FIG. 4.

To accompany Record 1966/165

Nichols (1965) illustrated and presented the petrology of some of the dolomites in the Sandover River area 100 miles south of the type area of the Camooweal Dolomite.

Brown (1965) presented a detailed log and petrographic analysis of the carbonate sequence in Lake Nash No. 1 well in the central part of the Georgina Basin.

In 1966, a graphic log of core-hole Grg 9A, 75 miles south-east of Grg 14, was prepared and this completed the study of part of the dolomite unit which extends across the south central part of the Basin (Nichols, 1966, p. 5).

Geologic Setting and Approach.

The carbonates of the Georgina Basin can be broadly divided into dolomites and limestones. The limestones generally crop out along the margins of the basin, while the dolomite crops out predominantly in the central and southern parts of the basin (fig. 4). Fossils were found at widely separated localities in these areas, and showed the carbonates to be of various ages from Lower Cambrian and Middle Cambrian to Lower Ordovician in different parts of the basin. Initially the dolomite unit which contains some thin interbeds of quartz sandstone, was portrayed as one unit, that is, the Camooweal Dolomite, extending over a large part of the Georgina Basin (Fig. 1 in Cambrian Geology of Queensland, and Fig. 2 in Cambrian Geology of the Northern Territory, Opik 1957). Later, more fossils were found as mapping progressed and the dolomite unit was subdivided, so that in the Avon Downs, Sandover River, Huckitta and Tobermory areas of the Georgina Basin, the dolomite is at present divided into Beds and Formations by boundaries separating different types of dolomite which are not constant laterally, but which contain fossils of different ages (Smith, 1964(b), p. 39).

It was considered undesirable to follow the current stratigraphic nomenclature in describing the petrography of the dolomite, as the subdivisions are subjective in their interpretation and are partly defined in terms of fossil faunas which are limited in occurrence and distribution. "Also, it is clearly unreasonable to expect stages to corres-

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pond to lithological boundaries, and it is better stratigraphic practice, now recommended by the Stratigraphic Committee of the International Geological Congress to distinguish strictly between lithostratigraphic and biostratigraphic units" (Ager and Evamy, 1963, p. 327).

Most of the detailed petrographic work was done on core-holes Grg 4, 14 and 9A, on dolomites which are approximately 1,000 - 1,700 feet above a folded quartz sandstone regarded as economic basement in the central and northern parts of the basin. However, information from stratigraphic wells which penetrated the succession is available, and the core and cuttings have been examined by the author. Consequently, it is proposed to include this information and give a general petrological description of the carbonates immediately above the basement, and add the descriptions and interpretations of adjacent units by other authors.

Nomenclature.

The majority of the carbonates in the Georgina Basin are dolomites, and the study of the dolomites and interpretation of the environment obviously involves the dolomite problem, in addition to all the problems imposed by the presence of textures and structures commonly found in limestones. None of these problems is completely resolved and they have formed the main topic at recent symposia in the United States.

The complexities of carbonate rocks are described by Ham and Pray (1962, p. 4), who state that "the outstanding distinctive aspects of carbonate rocks are their intrabasinal origin, their dependence on organic activity, and their susceptibility to post-depositional modification. In comparison, with other sedimentary rock families, moreover, the carbonate family is significantly polygenetic. And, finally, in addition to involving nearly every genetic process known to be important in sedimentation the carbonate rocks participate extensively in metamorphic processes of metasomatic replacement and recrystallisation."

The dolomite problem involves questions of primary precipitation, time of formation (penecontemporaneous or later diagenetic), chemistry and nomenclature. These were presented by Fairbridge (1957, p. 125), who reviewed the development of thought to that date, and by Illing, Wells and Taylor (1965, p. 89).

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Many new terms have been invented for limestone types, but there are few for types of dolomite. The terminology used here will be objective as far as possible, describing grade size, dominant grain or crystal, and type of matrix. These are basically the methods used by Grabau (1904, p. 228), Krynine (1948, p. 130) and Folk (1959, p. 1), although they are often subjective when referring only to clastic sediments. Equivalent limestone terms proposed by Folk (1959, p. 1) and Dunham (1962, p. 108), will be bracketed in apposition as they can indicate the original nature of the sediment, and although they are compounded words they are short and concise.

The following terms are used in a grade size-composition manner for limestones and refer only to the present state of the rock, for example, calcarenite does not always refer to clastic grains; it may also describe sand-size grains formed in situ, for example, mud aggregates (Purdy, 1963(b), p. 484). Similarly, dolomites are subdivided as follows:-

Microcrystalline dolomite - rock composed of dolomite crystals less than 1/16 mm in size.

Dololutite - rock composed of dolomite grains less than 1/16 mm in size.

Medium crystalline dolomite - rock composed of dolomite crystals 1/16-2mm in size.

Dolarenite - rock composed of dolomite grains of sand size (1/16 - 2mm) e.g. pellets, ooliths and composite grains.

Coarse crystalline dolomite - rock composed of dolomite crystals greater than 2 mm in size.

Dolorudite - rock composed of dolomite grains of rudite size (greater than 2 mm) e.g. pellets and composite grains, pisolites.

These terms are not used here to denote that the grains or crystals are derived particles of dolomite; the dolomite grains may be from re-worked dolomites, or re-worked limestones dolomitized at the present site.

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The term 'spar' is here restricted to describe clear crystalline calcite more than 10 microns in size, but does not denote pore-filling cement as implied by Folk (1962, p. 66), as similar textures can be produced during pore-filling and neomorphism (Folk, 1965, p. 43). Spar is used objectively in descriptions where its origin is unknown, and if pore-fill spar can be distinguished from neomorphic or recrystallisation spar, it is suggested that terms such as 'eospar' be used to describe initial or precipitated spar, and 'neospar' be used to describe secondary or neomorphic spar.

## PETROLOGY OF THE LIMESTONES

### Types and Components

(1) Microcrystalline limestone.

Petrography. Microcrystalline limestones in the northern part of the Georgina Basin (Randal and Brown, 1962(a), p. 19) generally occur as thin beds; knoll shaped structures have not been found. They are composed of microcrystalline calcite, generally in the range of 1 - 10 microns in size. Some varieties contain algal-stromatolite layers or sponge-like structures forming up to 10% of the rock. Some are partly dolomitic, argillaceous and possibly carbonaceous, and may contain up to 10% quartz, silt and fine sand. In rare samples, conglomeratic fragments of calcilutite occur in a matrix of microcrystalline calcite of 10 - 62 microns in size (microspar and pseudospar, Folk, 1965, p. 37, p. 42).

Microcrystalline limestone is broadly equivalent in grade size to calcilutite, aphanitic limestone, lithographic limestone and includes micrite (Folk, 1962, p. 65). It refers to limestones composed of microcrystalline calcite less than 62 microns in size.

Origin. Carbonate mud can originate in several ways; some of these have been discussed by Black (1933, p. 455) Lalou, (1957, p. 190), Cloud (1962, p. 1) and Purdy, (1963 (b), p. 492). A brief account of the different origins and the research workers is given by Folk (1965, p. 29) who lists:-

PLATE 1

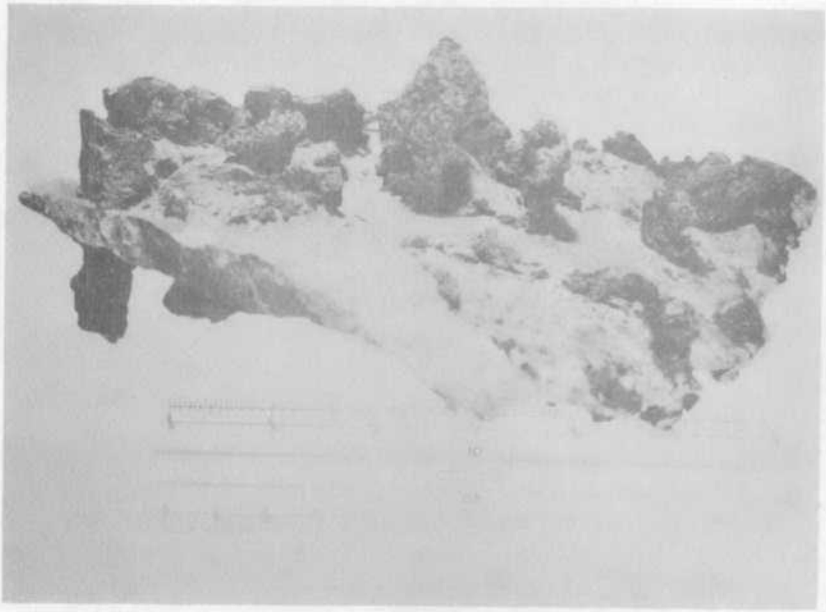

Fig. 1 Sponge(?) limestone. Anthony Lagoon Beds, Brunette Downs area. x ½ (File No. G/5419)

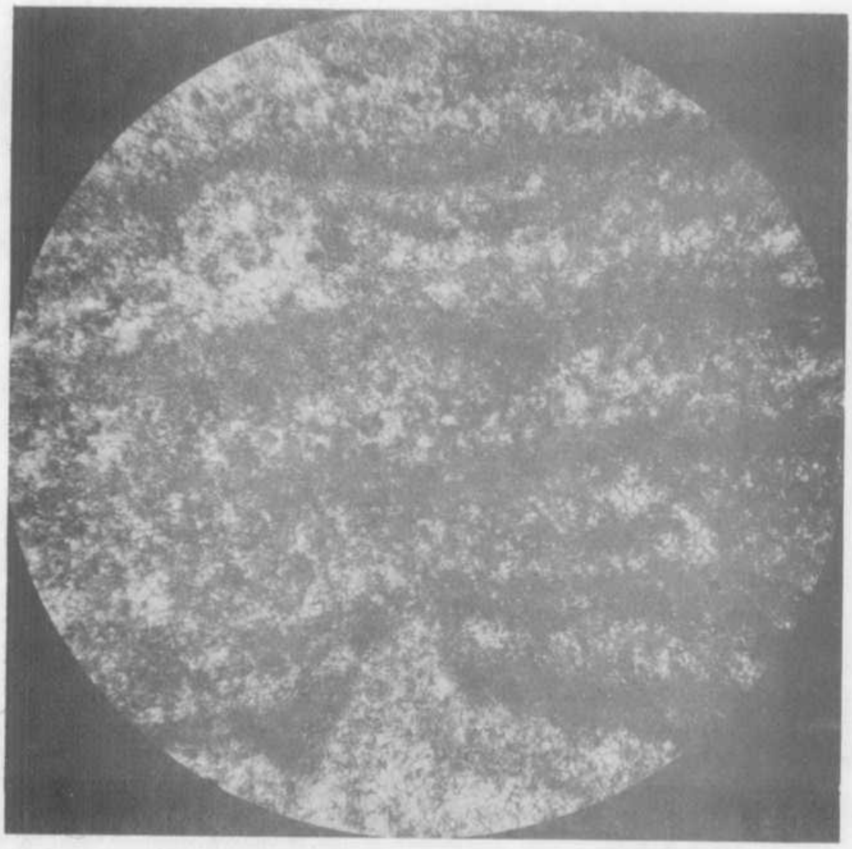

Fig. 2 Algal layering of microcrystalline calcite and interlayers of coarser recrystallised calcite. Anthony Lagoon Beds, Brunette Downs area. x45 (File No. G/5432)

(i) chemical precipitation, either inorganically or organically to give aragonite needles;

(ii) disintegration of certain algae produces aragonite needles similar to chemically precipitated needles;

(iii) disintegration of algally-secreted cocoliths, produces fine plate-like or rod-like calcite fragments;

(iv) abrasion of non-algal skeletal particles by action of waves, currents, living burrowers and crunchers, or rotting of organic tissue to release ultimate crystal units.

In the Georgina Basin, it is impossible to tell if the microcrystalline calcite has originated from any particular source. The sponge(?) and stromatolite limestones are not widespread but some may have provided the calcite. In some cases, flocculent textures in the calcite mudstones suggest disintegrated algal structures.

It appears that either chemical or organic precipitation, or algal disintegration were predominantly the sources for calcite mud, as there are few rocks with carbonate grains which could have been abraded. The environment was probably quiet, protected and shallow with waters supersaturated with $CaCo_3$, similar to the environment described by Cloud (1962, p.103).

(2) <u>Algal Stromatolite and Sponge(?) Limestones</u>. (Plate 1, fig.1)

<u>Petrography</u>. These limestones are autochthonous, and, in the Georgina Basin, the algal stromatolites are composed of layers of microcrystalline calcite (Plate 1. fig.2) occasionally with inter-layers of quartz sand, silt and pellets.

The sponge(?) limestone is partly dolomitic and comprises sponge-like forms of microcrystalline calcite, partly silicified, and surrounded by a mixture of calcarenite and calcilutite (Nichols, 1963, p.4). Irregularly shaped patches of microcrystalline calcite separated by drusy and granular, medium crystalline calcite, may represent disintegrated algal structures with the matrix possibly recrystallised to spar (Plate 2. fig.1).

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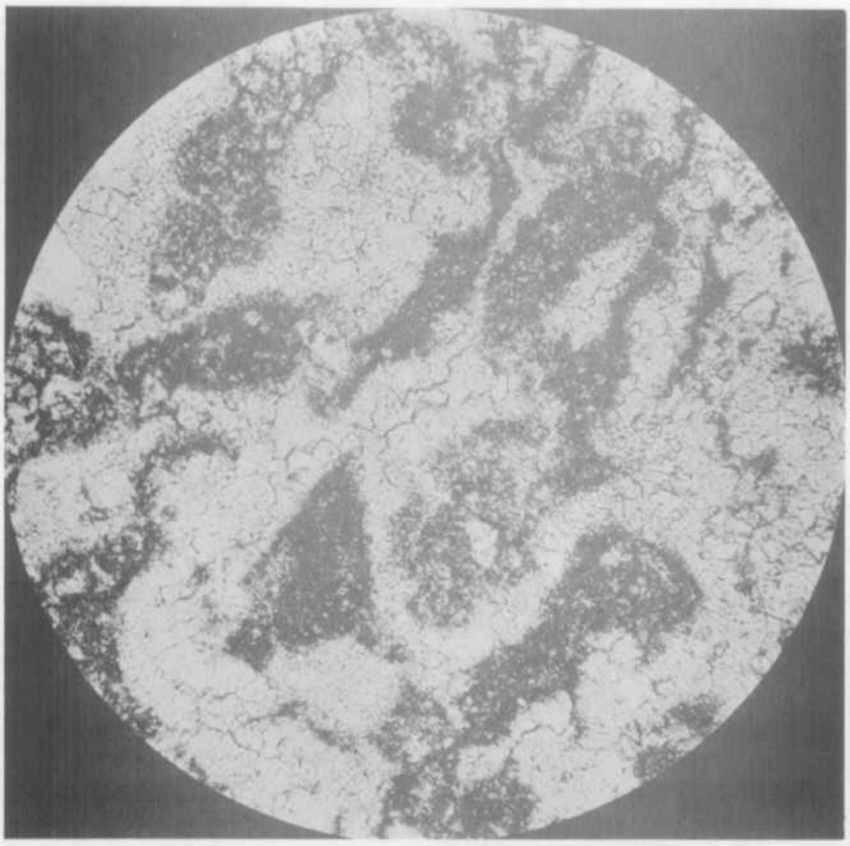

Fig. 1 Patches of microcrystalline calcite(algal?) with medium crystalline granular and drusy calcite(recrystallised?). Anthony Lagoon Beds, Brunette Downs area. x45 (File No. g/5440)

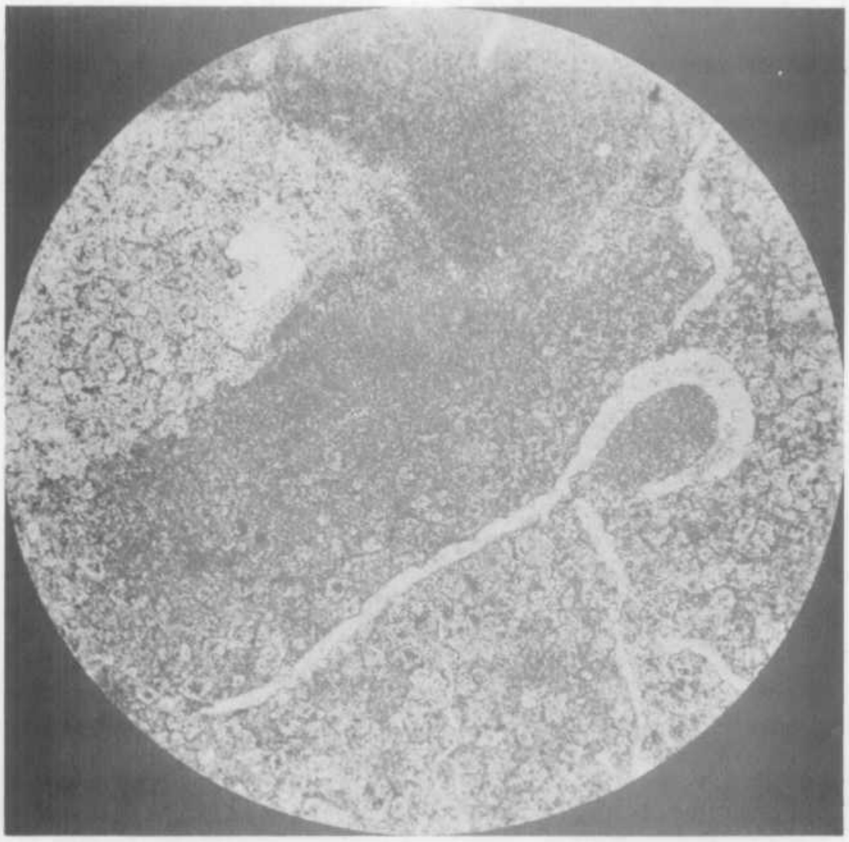

Fig. 2 Microcrystalline calcite with trilobite fragments partly replaced by equigranular, euhedral dolomite. Anthony Lagoon Beds, Brunette Downs area. x50 (File No. g/5438)

Origin. Varieties of algal stromatolites occurring at present are described by Logan, Rezak and Ginsburg (1964, p. 68) who conclude that the layered varieties formed as algal mats in an intertidal environment, while the oncolite varieties occur in the lower intertidal, agitated environment.

(3) Bioclastic limestones (Calcarenites, calcirudites) Plate 2. fig. 2).

Petrography. In the Georgina Basin, these limestones comprise shelly limestones with brachiopods, ostracods and trilobites, generally disarticulated, and limestones with Echinodermata remains and sponge spicules (Smith, 1964, p. 37; Randal and Brown, 1962(a), p. 18-19). The shells may be concentrated and cemented with drusy calcite cement to form a coquina (biosparite, biosparudite, Folk, 1959, p. 1) or scattered and mud-supported (biomicrite, biomicrudite, Folk, 1959, p. 1; wackestone, Dunham, 1962, p. 118). These types have been variously sorted and winnowed. They may be partly dolomitized and silicified and contain quartz sand, silt and clay.

Origin: Shelly limestones with disarticulated and fragmentary shells and other organic grains may be separated and broken by current or scavanging action. The shells may be cemented by drusy calcite while the Echinodermata fragments appear bound by syntaxial rim cement (Orme and Brown, 1963, p. 53). Recent research in present day marine environments indicates that cementation does not occur at the sediment-water interface today. Cementation seems to occur when the deposits have been exposed subaerially (Ginsburg, 1957, p. 96; Friedman, 1964, p. 777) or buried beneath later deposits, but still accessible to percolating solutions (Ginsburg, 1957, pp. 95-96).

The carbonate mud matrix around the bioclasts may be indigenous to the area, and the shells swept into it and deposited without any winnowing. Conversely, if the shells came to rest in a non-turbulent area, calcite mud may accumulate between them from algal or chemical precipitation.

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Generally, these bioclastic deposits occur in agitated zones on the edges of shelves or in lagoons (Newell and Rigby, 1957, p. 49), and along unprotected shorelines. Opik (1957(b), p. 41) thought this was the case with the above bioclastic limestones.

(4) Oolitic limestones (calcarenites).

Petrography. In the Georgina Basin these limestones are recorded by Smith (1964, p. 42) and Randal and Brown (1962(b), p. 18) and include all types with grains showing oolitic rims; the grains have been called oolites, ooliths and ooids (Purdy, 1963(a) p. 346). The rims are of variable thickness; some authors refer to "superficial ooliths", that is, grains with thin oolitic rims and "true ooliths" with thick oolitic rims (Illing, 1954, p. 1). The oolitic rims generally have a radial texture of fibrous calcite and concentric laminae of cryptocrystalline calcite, possibly of algal origin. The rims occur around the nucleus of either a pellet, quartz grain or shell fragment. The ooliths generally occur in a cement of fine to medium crystalline drusy and granular calcite (oosparite, Folk, 1962 p. 78), but on the Barkly Tableland (Randal and Brown, 1962(b), p. 18), they occur in a matrix of microcrystalline calcite (oomicrite, Folk, 1962, p. 76). The limestones may be partly dolomitised silicified and contain quartz, sand, silt and clay.

Origin. Oolites (the term for the sediment and the rock) generally form in areas where the sea water is supersaturated with CaCo3 and subjected to relatively strong current agitation (Newell, Purdy and Imbrie, 1960, p. 481), for example, on the edges of shallow shelves and banks, and in only six feet of water (as in the Bahamas). The turbulence in this environment prevents the formation of calcite mud or winnows what little might accumulate.

The ooids seem to be formed by the precipitation of aragonite crystals with c-axes oriented tangentially in concentric lamellae. Unoriented cryptocrystalline aragonite, generally more heavily pigmented, often occurs as discontinuous layers between the oriented lamellae and may result from "intersticial recrystallisation (and possibly precipitation) associated with organic matter incorporated in the grain" (Newell, Purdy and Imbrie, 1960, p. 481).

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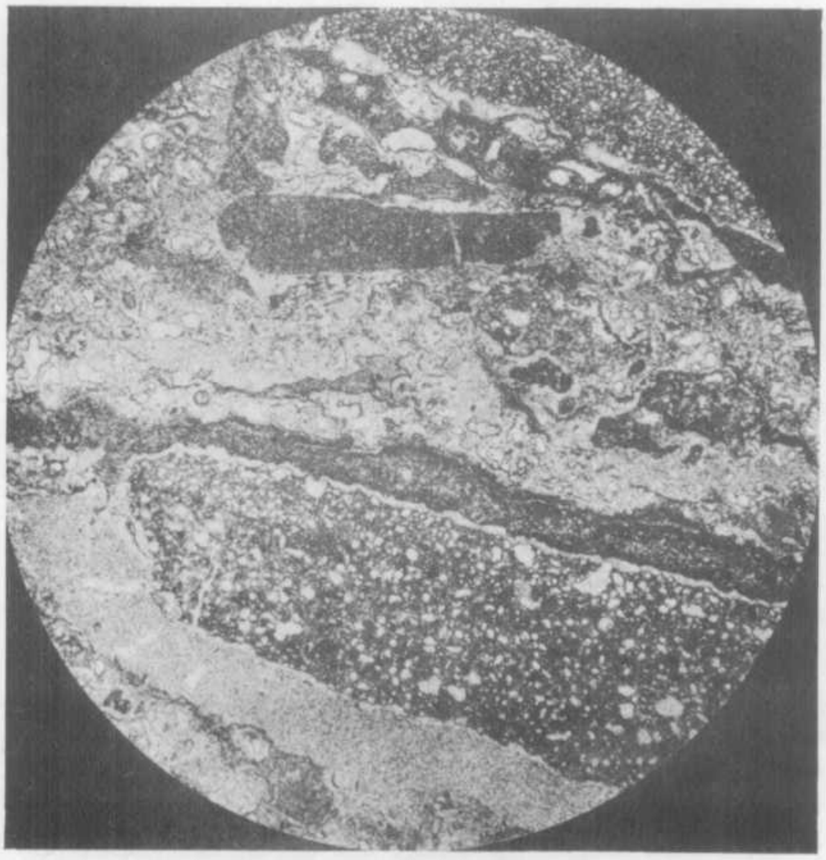

Fig. 1 Composite-grains of intraformational conglomerate in matrix of microcrystalline calcite. Anthony Lagoon Beds, Brunette Downs area x12 (File No. G/5427)

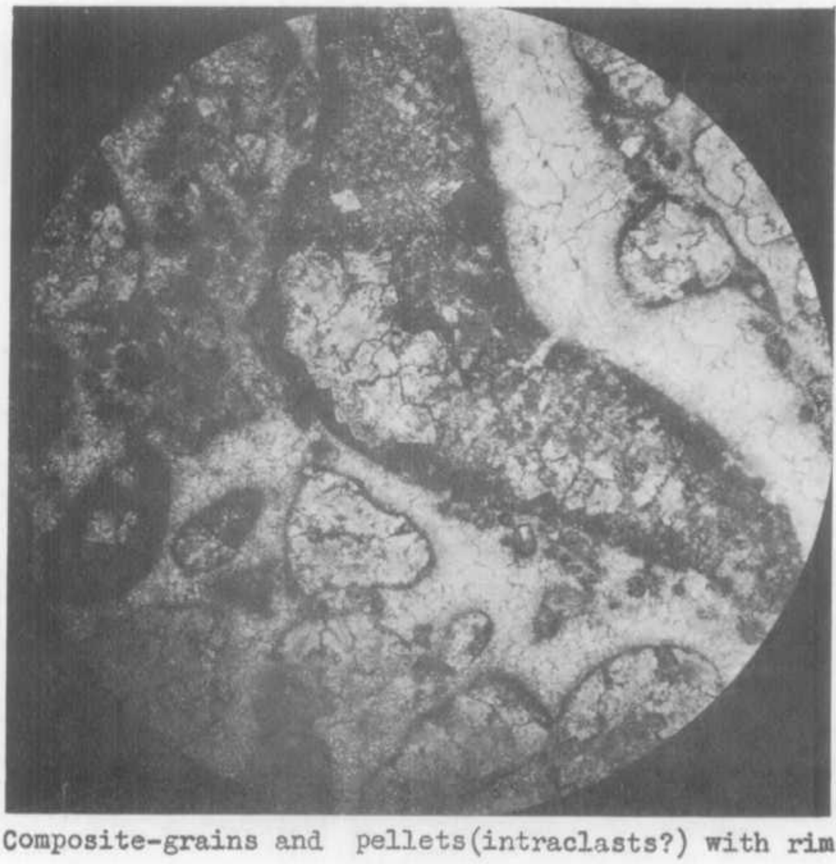

Fig. 2 Composite-grains and pellets(intraclasts?) with rims of microcrystalline calcite, partly replaced by inequigranular, poikilotopic dolomite, in medium crystalline granular and drusy calcite spar. Anthony Lagoon Beds, Brunette Downs area. x20 (File No. G/5430)

Later inversion and recrystallisation possibly converts the tangential aragonite to radial fibrous calcite.

Ooliths in a calcite mud matrix represent a diminution of oolitic accretion due to a decrease in bottom agitation and an increase in formation of calcite mud, or the transport of ooliths to an environment of calcite mud formation (Purdy, 1963(b), p. 479).

(5) Pelletal, composite-grain limestones (calcarenites, calcirudites). (Plate 3, figs. 1, 2).

These limestones comprise pellets, intraclasts, lumps and grapestone, in fine to medium crystalline, drusy and granular sparry calcite (pelsparite or pelsparudite and intrasparite or intrasparudite, Folk, 1959, p. 1), or in a matrix of microcrystalline calcite (pelicrite or pelmicrudite and intramicrite or intramicrudite, Folk, 1959, p. 1). Intraclasts comprise grains that have been sedimented, aggregated and reworked within the basin. The limestones may be partly dolomitized and may contain quartz sand, silt and clay. Limestones composed of extraclasts (Wolf, 1965, p. 1) are commonly called calclithites and comprise clasts from the hinterland whereas intraclasts are derived from within the basin of deposition. The former were not recorded in the Georgina Basin, but may be represented by intraformational pebble conglomerates (Randal and Brown, 1962(b), p. 18).

Pelletal limestones. The term pellet is confined to an aggregate of calcite mud with a spherical to ovoid form. Some authors place an arbitrary grade size of 0.15 mm. as the upper limit of pellet size, larger similar forms are termed intraclasts, as they are considered more likely to result from reworking of older sediments within a basin. However, larger pellets of faecal origin may be similar to intraclasts and these are also called pellets (Beales, 1965, p. 49). Again, some authors only refer to pellets as such if produced by organic or inorganic agglutination, but it seems difficult to determine this conclusively in examination.

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In the present study, all rocks are termed pelletal which comprise aggregates of calcite mud in spherical or ovoid form, regardless of size and mode of origin, as the size limit is arbitrary, and the mode of origin cannot always be determined either in hand specimen or in thin section. Pelletal limestones may be further subdivided into either faecal, intraclastic, or extraclastic when their origin is known.

Petrography. In the Georgina Basin limestones, pellets of varying size within sand grade often occur with bioclasts, ooliths and composite grains (Randal and Brown, 1962(b), p. 18). The pellets are set in a groundmass of sparry calcite which is often partly silicified. In other cases, fine grained calcite has been recrystallised into coarse calcite giving the rock the appearance of pellets in sparry calcite cement (Randal and Brown, 1962(b), p. 18).

Origin. The pellets in these limestones may be faecal pellets or mud aggregates (Purdy, 1963(b), p. 484), reworked partly consolidated calcite muds or pelletal sediments, disaggregated intraclasts (lumps or grapestone, Illing, 1954, p. 1), skeletal grains completely replaced by micritic carbonate (Bathurst, 1966, p. 15), and in some cases recrystallised ooliths. Each of these types may form in different environments depending on availability of the types and the bottom turbulence. Obviously, faecal pellets, mud aggregates and compound pellet clasts (intraclasts, grapestone, lump) require an original or potential calcite mud or silt environment from which the pellets can be produced by organisms or agglutinated by algal mucous or mucillage, and in which there is little bottom agitation until after the grains have formed. Subsequent agitation caused their break up into pellets. The size and uniformity of size of faecal pellets may have nothing to do with current strength, but is a consequence of the anal size of the organism. Scavenging by one species of organism can produce an apparently well sorted pelletal sediment independantly of current activity.

On the other hand, pellets formed from partly consolidated calcite mud and pelletal sediment may require more persistent and turbulent current action to be eroded and sorted, and would form probably in shallower and unprotected areas. These are possibly the principal type in parts of the Georgina Basin (Brown, 1962, p. 9) together with mud aggregates, as organic remains are rare.

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These two environments may be distinguished partly by petrographic characters of the pellets, and partly by the presence of either pore-fill cement or a calcite mud matrix which would indicate the degree of winnowing and current persistence, unless mixing of sediment layers by scavengers had occurred. However, these textures are not reliable indicators as recrystallisation or neomorphism of calcite mud (Folk, 1965, p. 43) can produce similar textures; this will be discussed later.

Composite-grain Limestones (Plate 3, figs. 1, 2). These limestones are composed of compound grains which may be produced by aggregation of particles or reworking of partly consolidated deposits. The aggregates are termed lumps and grapestone (Illing, 1954, p. 1) or intraclasts which refer to all sedimented, aggregated and reworked grains from within the basin of deposition (Folk, 1959, p. 1). Some of the intraclasts are difficult to distinguish from extraclasts (Wolf, 1965, p. 1) which come from erosion of a carbonate hinterland. The single grains of calcite mud can be confused with faecal pellets and aggregates of any number of pellets, ooliths, other intraclasts and skeletal grains, bound by calcite mud (intramicrite - micrudite, Folk, 1959, p. 1) or coarser crystalline calcite spar (intrasparite - sparudite, Folk, 1959, p. 1).

Petrography. In the north and north-eastern parts of the Georgina Basin, the composite grain limestones seem to be largely intraclasts, representing parts of adjacent deposits which have been eroded and deposited in large forset beds and around sponge (?) limestones (Nichols, 1963, p. 11). The composite grains contain quartz silt and sand, other pellets, ooliths and spherulites, and algal material.

Origin. The majority of the composite grains seem to be a product of erosion of earlier cemented sediments, by strong currents, but may also be derived from transport of agglutinated grains. Some composite-grains may form in situ by agglutination, being bound by either algal mucous, inorganically precipitated calcite mud or accumulated organic detritus (Purdy, 1963(b), p. 480). They form in areas of impersistent current activity which causes some concentration of grains but which is too weak to winnow the microcrystalline calcite. After cementation, subsequent reworking may winnow the sediment until it resembles a reworked partly consolidated sediment. The outline of grapestone is often undulating around grains and matrix or cement, but the outline of intraclasts from partly indurated sediments may be smooth, truncating grains, matrix or cement.

Studies of the matrix or cement binding the composite-grains provide clues to the degree of winnowing, sorting and derivation of grains, but must be combined with grain petrography studies.

Moreover, the field relationships of rocks with mixtures of composite grains in calcite mud must be linked with thin section studies as calcite mud layers can be thoroughly mixed into underlying, well-winnowed clastic sediment by burrowing scavengers.

## Inversion and Recrystallisation in Limestones

The terms recrystallisation, inversion and neomorphism involve many concepts (Folk, 1965, p. 21) for example, "1) mineralogical nature of the change. 2) state of the original fabric. 3) nature of the driving force. 4) direction of grain size change. 5) spacing of neuclii of growth. 6) nature of seeds, whether new grains or old ones."

Generally speaking, it is difficult to say if limestones were originally composed of aragonite or calcite, whether any aragonite crystals where inverted to calcite, whether recrystallisation proceeded via development of scattered coarser crystals to an anhedral crystalline mosaic, or via a gradual increase with the uniform crystal fabric at all times (Folk, 1965, p. 22).

Early workers, apart from Sorby (1879), generally described limestone in terms of crystallinity and fossils, but at various times since 1900, authors such as Grabau (1904), Cayeux (1935), Sander (1936) and Black (1938) have indicated the importance of studying grain size and depositional fabric.

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Some limestones consist of calcite mud with or without organic and inorganic grains; others consist of the same grains in crystalline calcite (coarser than 1/16th mm) in a variety of forms and size. Bathurst (1958, p. 11) distinguished between the crystalline mosaic produced by precipitation in an original void, and the mosaic produced by the recrystallisation, or grain growth, of a calcite mud. For example, drusy and granular cement were generally considered to form in original pore spaces, while anhedral crystals, with irregular boundaries and coarse crystalline patches in calcite mud, indicate recrystallisation (or grain growth).

Recently, however, Folk (1965, p. 43) suggested that drusy calcite and granular calcite may also be a product of recrystallisation (neomorphism), and must not be regarded as evidence of precipitation in a void. Furthermore with respect to these textures, the word "grain growth" (now abandoned by Bathurst) is incorrect and obscures the processes of recrystallisation when interpreted by analogy to fabric changes in metals (Folk, 1965, p. 19).

Some Georgina Basin limestones show mosaics of recrystallised calcite mud between intraclasts and skeletal fragments. There are two mosaics, varieties of pseudospar (Folk, 1965, p. 43): one comprises irregular-size crystals with crenulated boundaries and indented junctions with the calcite mud; the second variety is a syntaxial replacement rim (Orme and Brown, 1963, p. 53) where rims of calcite in optical continuity with crinoid fragments have replaced the calcite mud. Drusy and granular mosaics occur and in some cases, for example, grain-on-grain skeletal limestones, appear to be true pore-filling cement. However, in mud-supported skeletal limestones, drusy and granular mosaics may represent pore-filling in a partly winnowed limestone, or replacement of calcite mud (Folk, 1965, p. 43).

The recrystallisation mosaic may be equigranular with anhedral-subhedral crystals (xenotopic-hypidiotopic, Friedman, 1965, p. 646) or inequigranular with porphyritic, eudhedral to anhedral crystals (porphyrotopic, ideotopic - xenotopic fabric, Friedman, 1965, p. 646).

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The distinction between the similar fabrics which result from pore-filling and recrystallisation can only be made on their relationships to the gross fabric. Several authors have suggested this and a summary is given by Folk (1965, p. 44).

## PETROLOGY OF THE DOLOMITES

### Types and Components

Introduction.

The major rock unit in the Georgina Basin is a dolomite (variously called the Camooweal Dolomite, Arrinthrunga Formation, Meeta Beds and Ninmaroo Formation) which covers approximately 42,000 square miles and occupies most of the eastern half, and the south-western part. In section it varies from approximately 100 feet to 2,500 feet thick, its upper surface being the present day erosion surface, and in places immediately overlies the non-prospective zone for hydrocarbons (economic basement). Units of limestone often separate it from dolomite below and in some parts it contains thin interbeds of limestone, quartz sandstone and clay-siltstone (Fehr and Nichols, 1963, p. 9). The formation contains few fossils, but subsequent to it being published the Camooweal Dolomite (Opik, 1957(a)pp. 12-13, fig. 2), it was subdivided and mapped as Formations and Beds based on impersistent variations in dolomite lithology and the presence of a few fossils of different ages above and below the boundaries.

Detailed studies of part of the dolomite unit were made (fig. 3) and a tentative correlation proposed between core-holes Grg 14 and Grg 9A. The methods of approach are outlined in the section on Techniques for studying the carbonates; some results are given on the pictorial log (fig. 3), and the tentative correlations are shown on figures 6, 7 and 8.

The terms dololutite, dolarenite and dolorudite are here used objectively to describe composition and grade-size and do necessarily refer to dolomites of allochthonous origin. Where the origin of the dolomite is uncertain, but it forms more than 10 percent of the rock, Folk

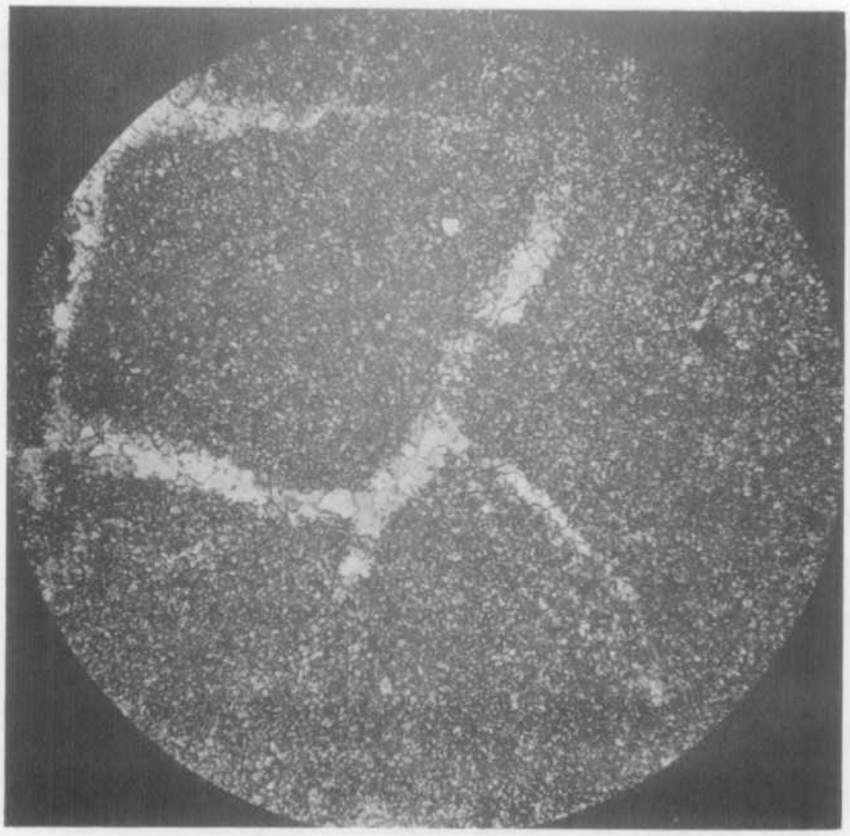

Fig. 1 Microcrystalline dolomite, slightly inequigranular, with veins of medium crystalline dolomite. Meeta Beds, Sandover River area. x30 (File No. g/8265)

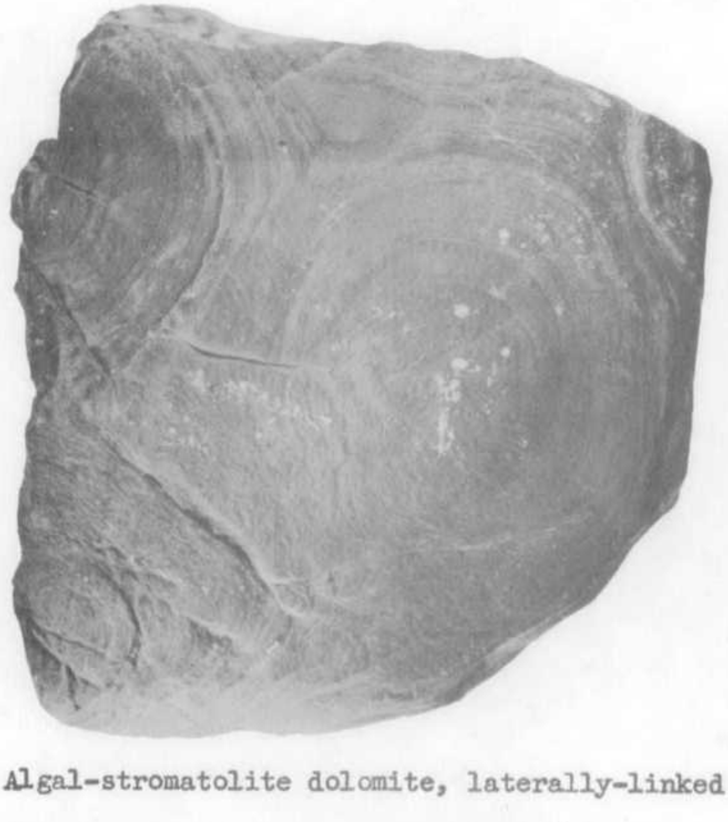

Fig. 2 Algal-stromatolite dolomite, laterally-linked columns, plan view. Meeta Beds, Sandover River area. x$\frac{3}{4}$ (File No. g/5420)

(1959, p. 1) proposed using dolomitic as a prefix, for example, dolomitic oosparite, but it implies a dolomitic limestone, and one with pore-fill spar, and not a dolomite. This is an objective method of description only if the "spar" part of the word has no genetic connotation, that is, implying formation in a void. For, in view of the similar fabrics produced by neomorphism, it seems that one must distinguish where possible between pore-filling spar and neomorphic spar in order to discuss environment of deposition.

The following types are broadly named then described more comprehensively in the text.

(1) Microcrystalline dolomite (Plate 4, fig. 1).

Petrography. The term dolomite is used for the rock and the mineral. This type of dolomite is equivalent in grade size to dololutite and finely crystalline dolomite, and is an abundant type of dolomite in parts of the Georgina Basin (Smith, 1964(b), pp. 41-43). It is composed of crystals of dolomite from 5-62 microns in size and forms a predominantly equigranular fabric of euhedral crystals (idiotopic, Friedman, 1965, p. 646). Some dolomites contain discontinuous layers of microcrystalline dolomite above scour surfaces, while others contain microcrystalline dolomite and flocculent patches of medium crystalline dolomite, possibly relict stromatolite and algal textures (Nichols, 1965, p. 9); faunal remains are rare and generally absent. Admixtures of quartz sand, silt and clay are also present. The dolomites are partly silicified, and were not originally cemented by silica (Randal and Brown, 1962(b), p. 18; Nichols, 1963, p. 20). Some nodules formed at the junction of bedding planes and joints.

These dolomites generally form thin beds with undulating surfaces, and rarely form lenses.

Origin. The origin of dolomite muds is still debated, and at present the author has found no evidence for their widespread formation by chemical precipitation in a present day marine environment. Baron (1960, p. 67) concludes after a series of experiments on the formation of protodolomite from precipitation and by diagenesis, that precipitated dolomites ought to be extremely rare in nature, owing to the high temperatures and pressures required, and may only exist if, and he quotes Strakov, the partial $CO_2$ pressure in the atmosphere was far higher in previous epochs.

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Cases for precipitation in saline lagoons are cited by Alderman and Skinner (1957, p. 561) and Skinner (1963, p. 449) who record active precipitation of apparently stoichiometric dolomite, and "protodolomite" which contains more calcium than the ideal dolomite. These dolomites formed in lagoons and their precipitation coincides with vigorous plant growth; the water closely approximates sea water in the relative amounts of the various salts in solution, but shows a wide range in salinity. Liskun and Devyatkin (1964, p. 44) describe primary dolomite from Neogene deposits of the Chuya Basin representing ".... a unique paragenesis of sediments which originated through large supplies of calcium and magnesium carbonate to a lake basin....". They quote Strakov who stated that dolomite is precipitated in slightly saline continental lakes of arid zones if the Mg content is sizeable, the reserves of alkaline are very large, and the pH is high (8.3). Reeves and Parry (1965, p. 606) however, state that the dolomite in West Texas pluvial lakes is formed by either primary chemical precipitation or penecontemporaneous alteration of calcite, and further, that dolomite cannot be demonstrated to form at surface temperatures in normal sea water.

After studying "so called primary and secondary dolostones" and determining C12/C13 ratios, aluminum and chloride contents (Weber, 1964(a), p. 1219) and trace element analyses for Al, Ba, Fe, K, Li, Zn and Na, Weber (1964(b), p. 1817) concluded that "some so called primary dolostones", not associated with evaporitic sediments are replacement products of fine grain calcite sediments under above-normal saline conditions.

At the present time, dolomite muds are forming in the Persian Gulf (Illing, Wells and Taylor, 1965, p. 89), Bonaire Netherlands Antilles (Deffeyes, Lucia and Weyl, 1965, p. 71) and Andros Island, Bahamas (Shinn, Ginsburg and Lloyd, 1965, p. 112). In each case, the dolomite muds occur near the surface in supratidal areas, affected intermittently by sea water, and are altered aragonite or calcite mud; some pellet, lime sand has also been dolomitised.

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In view of the meagre evidence for marine chemical precipitation of dolomite, it is assumed that calcite or aragonite muds were dolomitized soon after deposition, possibly within 3,000 years, and after sub-aerial exposure and that the calcite/aragonite was pseudomorphed by dolomite with preservation of the original texture. This is supported to some extent by Illing, Wells and Taylor (1965, p.89) who state that depositional textures only "tend to become obscured", but relic macroscopic and microscopic structures occur. Cryptocrystalline dolomite also occurs in the Bahamas and is produced by dolomitisation of a calcite mud (Shinn, Ginsburg and Lloyd, 1965, p.117). The hypothesis of penecontemporaneous dolomitisation in the Georgina Basin, to produce the Camooweal Dolomite (Brown, 1962, p.5) is supported, but modified to include sub-aerial exposure.

(2) Medium crystalline dolomite.

Petrography. This type generally forms thin beds (Nichols, 1965, p.7) and is composed of dolomite crystals between 1/16th mm - 1 mm in size, forming an inequigranular fabric of anhedral to euhedral crystals with porphyrotopic and rarely poikilotopic textures. Iron oxide specks are concentrated in the centre of crystals which often have clear rims. The fabric is structureless with no relic textures.

Origin. The origin is unknown, but may be a result of dolomitisation of any type of limestone, with obliteration of original textures, or the recrystallisation of a dolomite. It is assumed that it is a late diagenetic change of indurated sediment as there is a textural similarity to dolomite fabrics around faults and joint planes.

(3) Algal-stromatolite dolomite (Plate 4, fig. 2).

Petrography. These dolomites are autochthonous, occurring as beds and lenses varying from 6 inches to 2 feet in thickness and extending from several yards to 2 miles. They are generally columnar, the columns varying in diameter from one inch to two feet. Larger and different varieties occur which are colonial, domed forms from two feet to seven feet in diameter, composed of small columns half an inch in diameter disposed nearly horizontally at the edges of the colonies and vertically at the centre (R. R. Vine, B. M. R., pers. comm.). Similar small and large "algal colonies" occur in limestone interbeds in the dolomite unit in the south eastern part of the basin (Reynolds and Pritchard, 1964, p. 25). Coarse microconglomeratic dolomite occurs around stromatolite beds in the south-western part of the dolomite unit (E. N. Milligan, B. M. R. pers. comm.).

The stromatolitic algae in the central part of the dolomite unit are composed of alternating layers of equigranular, cryptocrystalline dolomite (less than 5 microns) and coarser inequigranular crystalline dolomite (5-62 microns). Some varieties have flocculent patches of coarser crystalline dolomite.

Algal dolomites are sometimes difficult to identify, but irregular, flocculent patches of microcrystalline and medium crystalline dolomite with undulating walls(?) of cryptocrystalline dolomite are tentatively included here.

The stromatolitic dolomites seem to have lost little of their columnar form and layered structure. However, the original presence of algal tubes or threads is indeterminable and it is only the clear presence of the columns and layers that suggests preservation of the original form.

Origin. At present, columnar laterally-linked algal stromatolites are forming in Shark Bay, Western Australia, generally in protected intertidal mud flats (Logan, Rezak and Ginsburg, 1964, p. 68). Further evidence for the intertidal origin and also for the preservation of texture after dolomitization is given by Illing, Wells and Taylor (1965, p. 93) from the Persian Gulf. The preservation of primary structure and fabric in other types of dolomite is described by Murray (1964, p. 388). It is postulated that the Georgina Basin, algal-stromatolites formed in similar environments, and that shallow, sunlit, often intertidal areas developed at different times and places. This is partly supported by the presence of intraformational breccias, thin, ripple-marked quartz sandstone, and finely crystalline dolomite textures.

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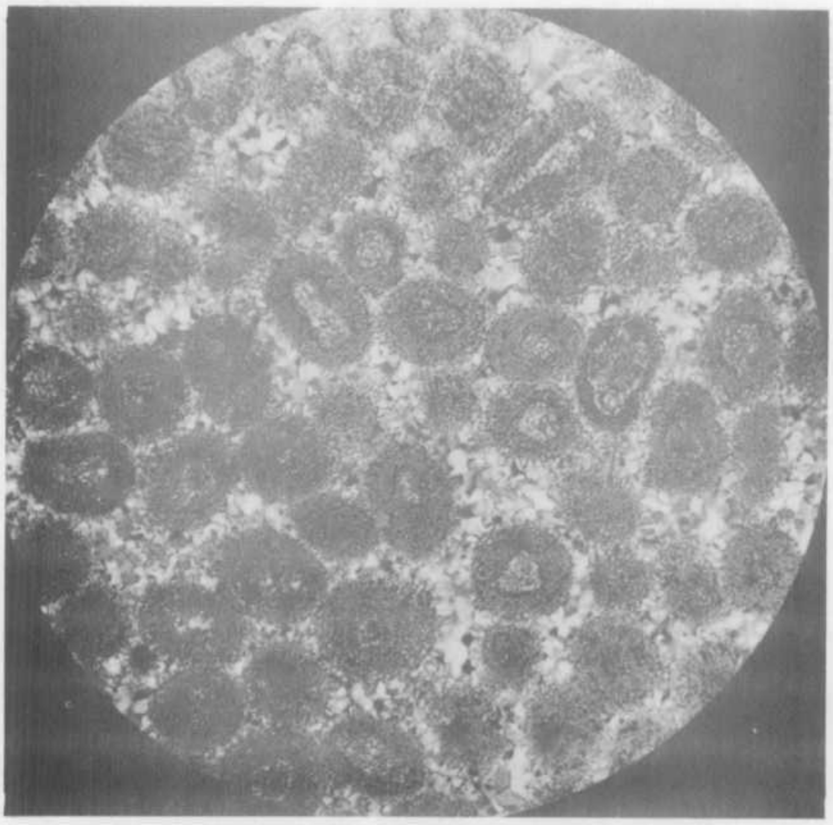

Fig. 1 Oolitic chert with ooliths of microcrystalline silica in medium crystalline drusy silica. Tomahawk Beds, Sandover River area. x45 (File No. g/8189)

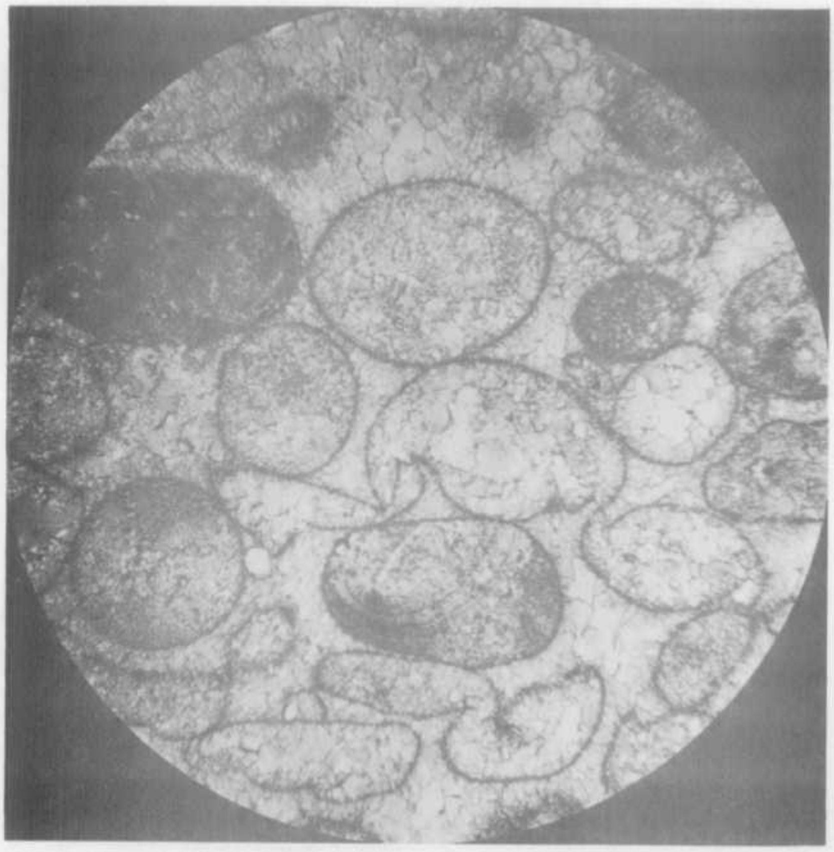

Fig. 2 Composite-grain and pellet dolomite with compacted, broken pellets, leached and infilled with spar or recrystallised to granular and drusy spar leaving microcrystalline dolomite rim(micrite envelope?), in granular and drusy dolomite spar. Abraded ooliths and pellets form composite-grains. Meeta Beds, Sandover River area. x45 (File No. g/8268)

(4) Bioclastic dolomites.

Petrography. Dolomites with archaeocyathids and brachiopods are here considered to occur in the south-western part of the basin (Smith, 1964, p. 33). In other cases, rare hyolithids brachiopods and gastropods occur higher in the dolomite (Smith, 1964, p. 34; Nichols, 1964, p. 10). In some cases the fossils are well preserved, but some gastropods are recrystallised and unidentifiable. The latter occur with composite-grains and pellets in granular and drusy dolomite spar.

Origin. Few fossils have been found in the dolomite and it is assumed that the predominance of microcrystalline, pelletal, oolitic and composite-grain sediments implies a predominantly chemical environment inimical to animal life.

(5) Oolitic dolomites (dolarenites).

Petrography. These dolomites, which are rare in the north and central parts of the basin (fig. 5), consist of ooliths with and without rare pellets and composite-grains in a matrix of microcrystalline dolomite and dolomite spar. Some are abraded and form parts of composite-grains (Plate 5, fig. 2). The oolitic rims are generally 60 microns thick and the concentric layering and radial fibrous texture is evident. Superficial and true ooliths (Illing, 1954, p. 1) also occur; the nucleus, generally a pellet, and the rims are often partly recrystallised (Brown, 1962, p. 9); quartz sand grains rarely form a nucleus, but admixtures of quartz-sand are found. Some oolitic chert has the original textures preserved and possibly the original crystalline calcite pseudomorphed by silica (Nichols, 1965, p. 11) (Plate 5, fig. 1).

Purdy (1963(a), p. 348) records completely recrystallised cryptocrystalline calcium carbonate ooids from the Bahamas where the original texture is almost completely destroyed. Consequently, pelletal looking rocks must be carefully examined for "ghost" textures. Only in two cases (Plate 5, fig. 2; Plate 6, fig. 1) were pelletal dolomites greatly recrystallised, and consequently it was impossible to determine any texture.

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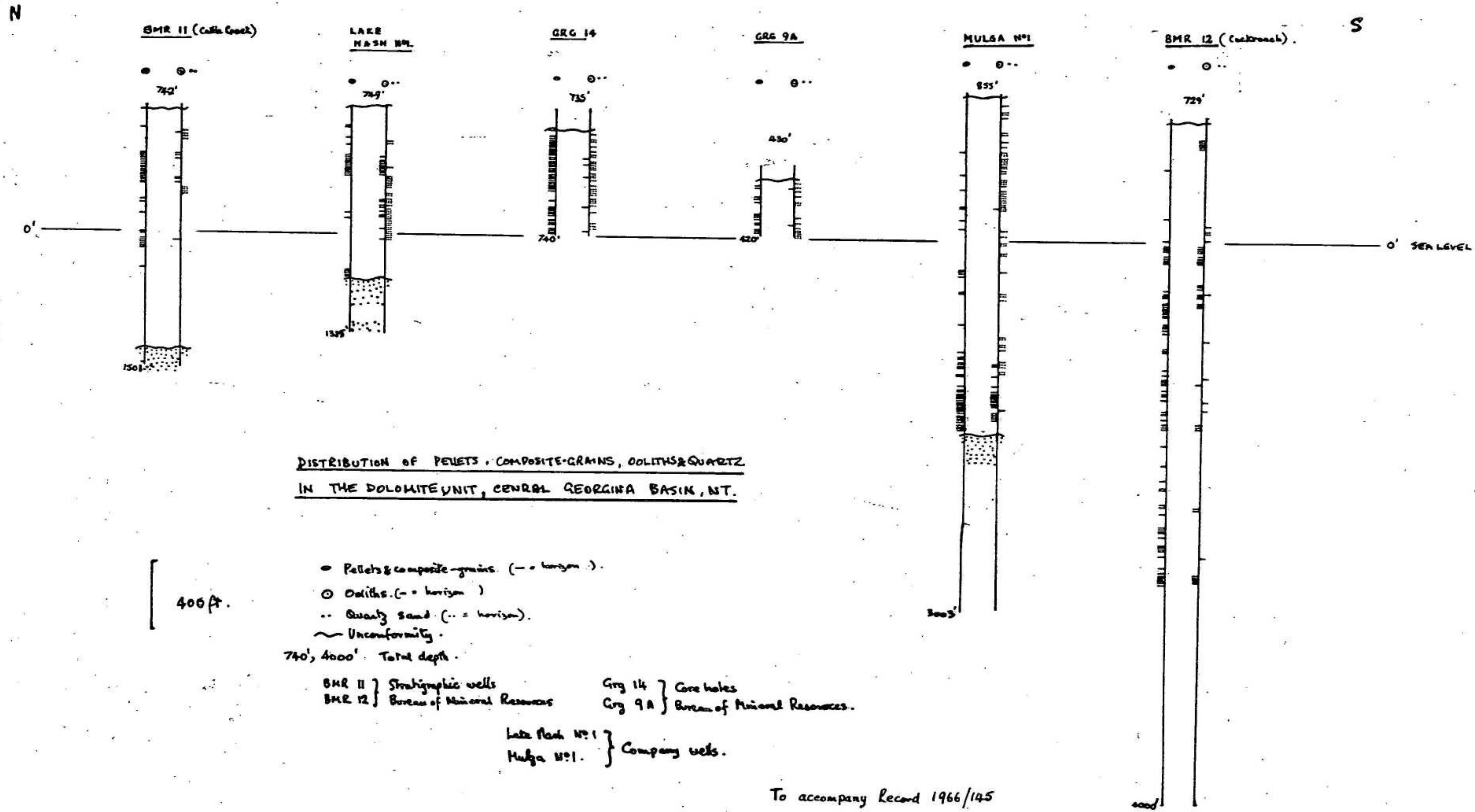
FIG. 5.




DISTRIBUTION OF PELLETS, COMPOSITE-GRAINS, OOLITHS & QUARTZ IN THE DOLOMITE UNIT, CENTRAL GEORGINA BASIN, NT.

To accompany Record 1966/145

Origin. The oolitic dolomites were probably oolitic lime sands. Similar fabric textures occur and the dolomite-ooliths occur in microcrystalline or sparry dolomite. In many cases, the sparry dolomite forms a subhedral to anhedral groundmass and drusy crystals rarely occur. It is assumed that these rocks formed as oolitic limestones and under the same conditions as their limestone counterparts (Newell, Purdy and Imbrie, 1960, p. 481). It is assumed that they were later dolomitised to produce the present texture, possibly under subaerial conditions.

(6) Pelletal and Composite-grain dolomites (dolarenites, dolorudites).

These types are more abundant than the oolitic types in the north and central parts of the Georgina Basin (fig. 5) and comprise pellets and composite-grains of microcrystalline, pelletal and oolitic dolomites in granular and drusy dolomite spar (Nichols, 1965, p. 7-8), or in a matrix of microcrystalline dolomite, or in a mixture of spar and mud with admixtures of quartz sand. These types of dolomite are similar to the pelletal and composite-grain limestones, and possibly formed as pelletal and composite-grain lime sands and rudites. There is no evidence of widespread dolomite precipitation under present day marine conditions and the type of dolomitisation and origin of drusy and granular dolomite spar is one of the most important aspects of the study. It involves the determination of:

(i) whether the grains formed in an environment of high energy and pore spaces were filled with drusy dolomite, or in a low energy environment containing carbonate mud which was subsequently recrystallised to drusy-granular texture.

(ii) whether the grains and ground mass were originally dolomite, or calcite which has been dolomitised and recrystallised or pseudomorphed.

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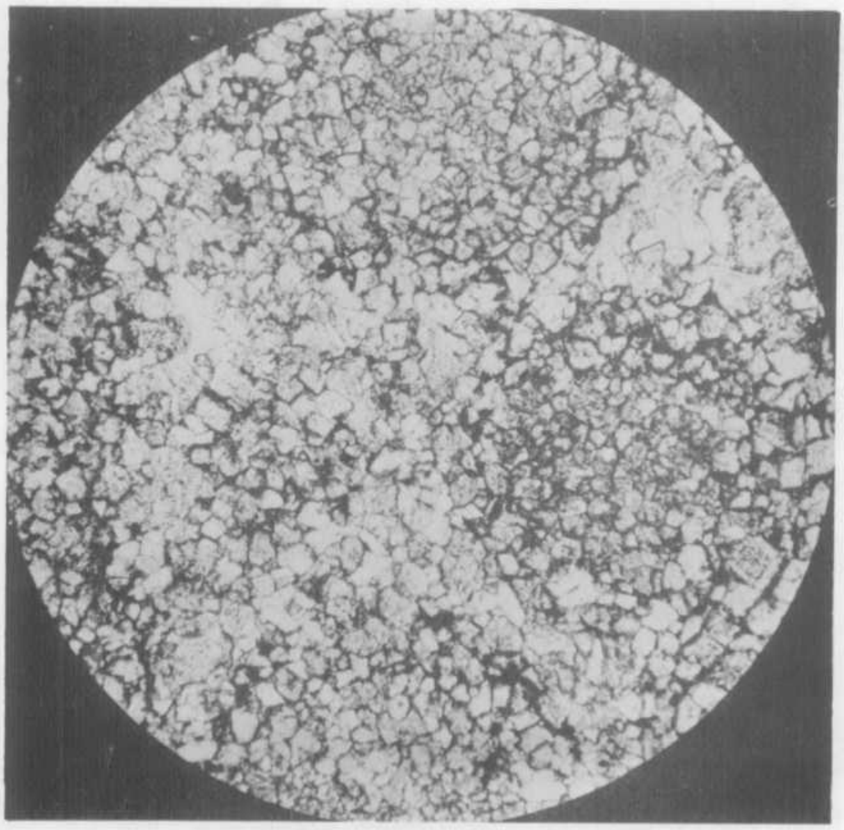

Fig. 1 Pellet(?) dolomite with large circular patches of equigranular dolomite rhombs, outlined by iron oxide and coarser dolomite rhombs, in mixed rhombic dolomite and anhedral calcite spar. Tomahawk Beds, Sandover River area. x45(File No. g/8190)

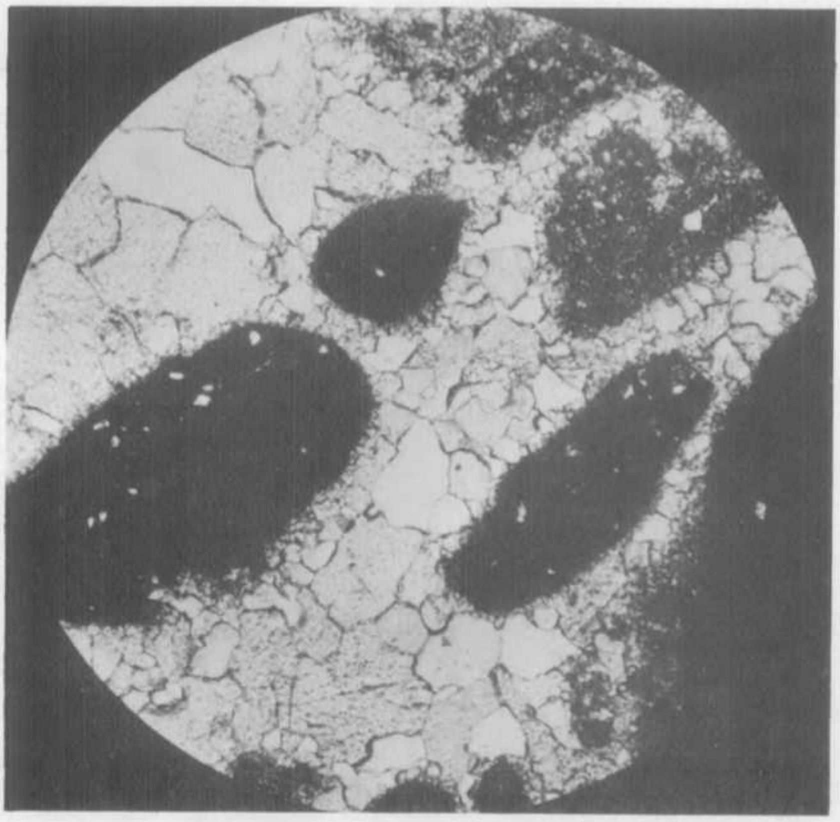

Fig. 2 Composite-grain dolomite with grains of microcrystalline dolomite partly recrystallised, and quartz silt, in medium to coarse drusy and anhedral dolomite spar; matrix-supported(?), recrystallised to drusy spar around grains(?), pseudomorphed by dolomite(?). Meeta Beds, Sandover River area. x 30 (File No. g/8195)

(a) Pelletal dolomites (Plate 5, fig. 2; Plate 6, fig. 1).

Petrography. The pellets are generally spherical and well-rounded, and are composed of microcrystalline dolomite. Pellets show no internal structure; they occur in both a microcrystalline and sparry dolomite ground mass. Those in a microcrystalline matrix are similar to their limestone equivalents, except that faecal pellets are unlikely in the Georgina Basin dolomites as fossils have not been found with or near the pellets.

Origin. As there is no evidence for widespread formation of pelletal dolomites in present marine environments, it is thought they accumulated as pelletal lime sands and rudites, and were penecontemporaneously dolomitised; they may have formed in a manner similar to that described by Deffeyes Lucia and Weyl (1965, p. 71).

Dolomites with pellets apparently cemented by drusy dolomite spar possibly accumulated as pellet lime sands and rudites in an area of current activity which winnowed the sediment or prevented mud from being deposited. It is postulated that drusy and granular calcite cement was precipitated and later dolomitised, the original textures being preserved. In cases where relict patches of microcrystalline dolomite occur or the pellets are spar-supported, the texture possibly resulted from incomplete winnowing and recrystallisation; with mixed textures it is impossible to determine which process was involved.

(b) Composite-grain dolomites.

Petrography. These dolomites are composed of composite grains of variable sphericity and roundness, in microcrystalline or sparry dolomite. The composite dolomite grains are generally composed of ooliths and pellets in microcrystalline dolomite or coarser crystalline dolomite spar. The composite grains are spherical and ovoid in shape, occasionally raft-like, well rounded and in some cases abraded, for example, ooliths may be truncated (Plate 5, fig. 2). They do not always form a grain-on-grain texture (c.f. Dunham, 1962, p. 110, plate 2A), but are often separated by granular and drusy, medium crystalline dolomite spar (Plate 6, fig. 2). The majority of composite grains, however, show grain-on-grain texture and are set in microcrystalline dolomite or granular and drusy dolomite spar. Brown (1962, p. 6) described some from the north-east part of the basin, with dolomite rhombs forming spar, and occurring in large cross-beds.

Admixtures of quartz sand and silt, and angular chert grains occur with the composite grains.

Origin. Dolomites with composite-grains in a mud matrix may be reworked partly consolidated oolitic and pelletal sediments which were deposited in an area of mud accumulation, or be aggregated and agglutinated grains in an area of mud formation. The rarity of organic remains precludes the downward-working of mud layers by organisms into pellet sands and rudites. Some dolomite composite-grains in dolomite mud (Brown, 1962, p. 14) occur in large cross-beds in the north-east part of the dolomite unit and although denoting strong current activity, the lack of winnowing implies that the currents were possibly of a "dumping" character.

For the most part, the composite-grains in a mud matrix formed probably as lime sands and rudites in shallow water where low current energy and little winnowing prevailed. The particle size may reflect current strength, but may also only represent the stage reached during aggregation. Dolomitisation possibly occurred soon after deposition; and apparently few textures were destroyed.

Dolomite composite grains in granular and drusy dolomite spar together with pellets of oval shape occur, and Brown (1962, p. 6) described some from large cross-beds which have quartz sand admixtures and were obviously deposited in a high energy environment. Similar types also form thin beds and possibly lenses; they show average sorting, are often well rounded and some show signs of abrasion. These also probably formed in a high energy environment, but possibly as banks or shoals; however, the shoal shape cannot be fully determined in the field. The grain-on-grain texture indicates that the drusy dolomite spar could represent pore-filling cement, but as there is little evidence of widespread precipitation of dolomite in present marine conditions, it is assumed that

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composite-grain lime sands and rudites accumulated, were cemented and then dolomitized. Some pelletal and composite-grains of sub-spherical and ovoid shape in drusy and granular dolomite spar do not form grain-on-grain texture; the matrix was possibly recrystallised and then dolomitised, rather than the grains being forced apart during cementation.

(7) Conglomeratic dolomites (dolorudites).

Petrography. In one sample sub-rounded grains of microcrystalline dolomite and angular grains of chert occur in a matrix of microcrystalline dolomite. In other samples, raft-like grains occur adjacent to each other and appear to be broken thin beds, or carbonate flakes described by Purdy (1963(b), p. 481).

Origin. The origin of the dolomite and chert grains is unknown, but they are assumed to be derived from erosion of pene-contemporary deposits, as older silicified dolomites are rare. The grains possibly were transported from land and may denote a period of uplift and erosion. The raft-like grains on the other hand may be from sub-aerial erosion, or from consolidation on the sea floor, or from the break-up of incipiently bedded deposits.

## Recrystallisation and dolomitisation

In most cases the grain textures, microcrystalline dolomite matrix and dolomite spar are clearly defined. The problems concerning these textures are as follows. The grains may represent:-

(1) Derived or aggregated-in-place grains of dolomite.

(2) Derived or aggregated-in-place grains of limestone, later dolomitised.

The drusy and granular dolomite spar may have originated as:-

(1) Porefill precipitated dolomite cement.

(2) Microcrystalline dolomite matrix recrystallised (neomorphosed) to produce spar texture.

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(3) Porefill precipitated aragonite or calcite spar later pseudomorphed by dolomite.

(4) Microcrystalline calcite matrix recrystallised to produce spar texture, later pseudomorphed by dolomite.

The occurrence of composite grains, pellets and ooliths in the lower, middle and upper parts of the dolomite unit with there being no dolomite source rock in the hinterland implies formation within the basin. The dolomite unit is of formational extent and is not associated with evaporites; it falls in the category of dolomites formed by regional dolomitisation (Fairbridge, 1957, p. 153).

The clarity of most of the grain and algal textures and preservation of sedimentary structures, such as cross-bedding and scour and fill, distinguishes these dolomites from dolomites which have medium and coarsely crystalline textures and obliterated grain or microcrystalline textures.

As there is no evidence of dolomites forming on a large scale at present in submarine conditions, it is assumed that these dolomites are a result of dolomitisation, during which the original textures were preserved by the pseudomorphing of calcite fabrics and textures (Murray, 1964, p. 398).

Furthermore, in apparently clastic dolomites with grains of spherical, sub-spherical and ovoid shapes and without grain-on-grain textures, it seems impossible to have pore-fill drusy and granular spar textures by any means other than recrystallisation. Again, as evidence for present day dolomite pore-fill is lacking, an alternative process of recrystallisation of a calcite mud to produce a drusy-granular texture (needing only a line or surface of discontinuity along which to form (Folk, 1965, p. 44)), and subsequent pseudomorphing during dolomitisation provides the answer.

According to Fairbridge (1957, p. 153) regional dolomitisation is believed to have occurred on the sea floor either rapidly or in stages, and to have reached completion penecontemporaneously under submarine sedimentary conditions. But he states that obliteration of

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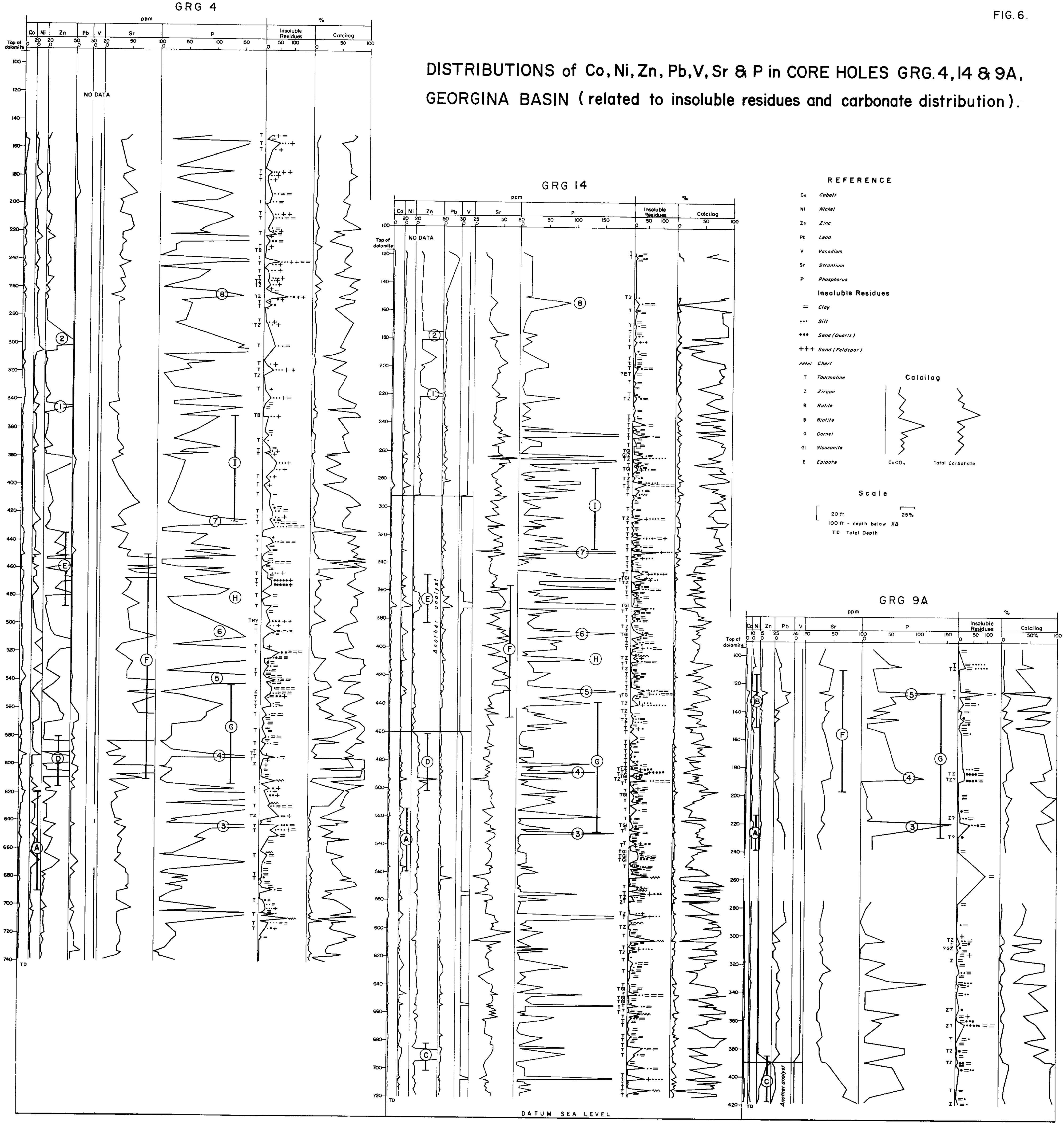
FIG. 6.




DISTRIBUTIONS of Co, Ni, Zn, Pb, V, Sr & P in CORE HOLES GRG. 4, 14 & 9A, GEORGINA BASIN (related to insoluble residues and carbonate distribution).

*Bureau of Mineral Resources, Geology and Geophysics.* *August 1966.* *To accompany Record 1966/145.* F53/A8/13 EJ structures and fossils could occur, and features such as sun-cracks and tidal flat structures are described; these are partly sub-aerial environments rather than sea floor environments.

Illing, Wells and Taylor (1955, p. 89) however, state that partial preservation of textures occurs in intertidal sediments dolomitised during approximately the last 3,000 years. Shinn, Ginnsburg and Lloyd (1965, p. 117) support this with evidence of preservation of laminae, similar to those associated with algal mats, and pellets some of which "are quite distinct." These examples resemble dolomites in the dolomite unit of the Georgina Basin, and may provide clues for interpreting the significance of these ancient dolomites.

The type and extent of dolomitisation does not seem to resemble the pattern postulated by Adams and Rhodes (1960, p. 1914) for a restricted shelf environment where local lagoons are established which coincide with local areas of dolomite. In the Georgina Basin, although shoals and patch reefs of stromatolites are postulated, these are not locally dolomitised, neither do evaporites occur in the sequence. Some restriction of circulation and increased salinity possibly occurred in the western part of the basin where chlorite and corrensite clay minerals were found in parts of the sequence.

## TRACE ELEMENT AND CLAY MINERAL STUDY

### Distribution of selected trace elements in parts of the dolomite unit

#### Introduction.

Samples of the dolomites from core-holes Grg. 4, 14 and 9A in the Georgina Basin which were petrographically studied, were also sent to the Australian Mineral Development Laboratories to be analysed for Co, Ni, Zn, Pb, V, Sr and P. The distribution of these elements was plotted against insoluble residues and calcilog distributions (fig. 6) to investigate their use as correlation parameters, although the possibility of this is considered doubtful (Turekian, 1963, p. 15).

Co, Ni, Zn, Pb, and V were selected by A. D. Haldane (Sen. Chemist, B. M. R.) after a discussion concerning the rock units, the probable environment of deposition, and the question of which elements might be widely distributed, Sr was included to investigate its distribution in unfossiliferous dolomite and minor limestone interbeds; and P was included to help in the search for phosphate.

The core-holes are approximately 70 miles apart in a general WNW - ESE line across the central part of the Georgina Basin. They were drilled in the dolomite unit, and the petrographic and geochemical projects were designed to determine if correlation was possible between the holes.

Representative samples of the micro-facies in the dolomite were crushed and sent to the Australian Mineral Development Laboratories and were analysed by D. Bowditch, M.R. Hanckel, R Wilson Smith and H. Kresse.

<u>Distribution of elements.</u>

1) <u>Grg. 9A</u> <u>Dolomite</u> (96-432'); <u>57 samples</u>.

The variation and general amounts of elements are given below.

<u>Cobalt</u>; 2-17ppm, generally 2ppm.

<u>Nickel</u>; 2-13ppm, generally between 2-5ppm.

<u>Zinc</u>; 1-26ppm, generally between 1-3ppm; three samples contain 16, 23, & 26ppm, recorded by a different analyst.

<u>Lead</u>; 3-30ppm, generally grouped into 3ppm; 9 and 13ppm; and 20 and 25ppm.

<u>Vanadium</u>; 10- 20ppm, 20ppm for the majority, but a different analyst records six samples with 10ppm.

<u>Strontium</u>; 18-97ppm, generally 30 and 35ppm, with rare ones at 25 and 42ppm; six samples contain 34-97ppm recorded by a different analyst.

<u>Phosphorous</u>; 10-160ppm, generally 10-50ppm, with five samples between 70-75ppm, and only four with over 100ppm.

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2) Grg. 14. Dolomite (117'6" - 720'4"); 299 samples.

The variation and general amounts of elements are shown below.

Cobalt; 2-12ppm, generally 2ppm, some at 2ppm and few at 3, 4, 5, 6, 9, 11, 12ppm.

Nickel; 2-24ppm, generally 2-2ppm, some between 3-11, six at 12, 14, 15, 16ppm, and one at 24ppm.

Zinc; 1-300ppm, generally 8-15ppm, with six at 300, 250, 148, 131, 49 and 46ppm. A different analyst records a relatively low abundance of generally 1-3ppm in the middle of the sequence of 8-15ppm.

Lead; 3-25ppm, generally 2-3ppm, some between 5-10ppm, and six between 15-25ppm.

Vanadium; 10-200ppm, generally 20ppm, with four samples at 30, 50, 60, and 200ppm. A different analyst records an interval of 10ppm in the middle of the sequence of 20ppm.

Strontium; 11-100ppm, generally 25-45ppm, with some between 50-60ppm, and a group between 60-70ppm in the middle of the sequence.

Phosphorus; 5-390ppm, generally below 75ppm (between 5-40ppm) some between 50-100ppm, twenty-four between 100-300ppm, and three between 300-400ppm.

3) Grg.. 4 Dolomite; minor dolomitic claystone and siltstone and limestone (91'4" - 739'); 161 samples.

The variations and general amounts of elements are given below.

Cobalt; 2-14ppm, generally 2-5ppm, some 5-7ppm, two at 11ppm and one at 14ppm.

Nickel; 2-14ppm, generally 2-5ppm, some 5-10ppm, nine between 10-15ppm, seven between 15-20ppm, and five samples between 20-30ppm.

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Zinc; 1-640ppm, generally 3-10ppm, with several groups between 10-30ppm, some isolated peaks between 55-65ppm, and a group of 210, 520 and 640ppm.
Lead; 3-20ppm, generally 3ppm with some at 3, 7, 9, 12ppm, five at 15ppm and one at 20ppm.
Vanadium; 20ppm; twelve samples had insufficient material for V determination.
Strontium; 10-840ppm, generally between 15-50ppm (35ppm); some between 50-70ppm, and groups of four or five samples in the middle of the sequence at 175 and 250ppm; 190, 310, 350, 370, 640 and 840ppm; and 120, 350 and 640ppm.
Phosphorus; 0-360ppm, generally below 75ppm (between 10-50ppm), twenty-eight between 100-150ppm, eight samples between 200-300ppm, and two at 340 and 360ppm respectively.

Validity and relationship of elements.

The majority of results have to be accepted at face value as there was no method of checking their accuracy. However, adjacent samples were submitted and more strontium and phosphorus (determined by X-ray fluorescence and colourimetry) occurred in samples submitted in 1964 than in samples submitted in 1965 (the latter were determined by atomic absorption and colourimetry). In some cases there are marked reversals.

Other variations in accuracy were found in analyses for Grg. 14 where the vertical distribution of some elements shows marked changes to a lower order of maxima when the analyst changes, and certain peaks in the lower order correspond to the general order of maxima obtained by the other analyst.

The accuracy or validity of the results is thus suspect. It was decided to use the results of the strontium and phosphorus where determined with the other elements by atomic absorption, ignoring the earlier results, and to mark the changes coincident with the change of

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analyst; it is assumed that maxima in the lower order range would also be maxima if determined by the analyst giving higher order results. The possible utility of the elements follows.

Lead content ( 3-30ppm) in the dolomites is too low to be of any value.

Vanadium content ( 10- 20ppm) is normally low in carbonates ( 10ppm, Rankama and Sahama, (1950, p. 601)), and was included in the study in the hope that it would provide marker horizons if present. In the core holes, it is always less than 20ppm or less than 10ppm, differing with the different analysts, except in Grg 14 where it coincides with marked increases in clay, quartz silt and sand, and at some levels, feldspar sand. However, it does not occur at all horizons high in these insolubles.

Cobalt ( 2-14ppm) and Nickel ( 2-24ppm) amounts, though small, show obvious maxima and minima, and in some cases, intervals showing similar ranges occur in each core hole. Often one element reflects the other and is also reflected by zinc and phosphorus, but not by lead, vanadium or strontium.

Zinc ( 1-640ppm) amounts show distinct maxima against a generally low background ( 3-10ppm); groups of maxima and individual peaks occur in each core hole and may represent equivalent stratigraphic intervals.

Strontium (10-840ppm) content though generally low (15-50ppm) is more abundant in the middle of the sections of Grg 4 and 14, but only slightly so in Grg 9A. The maxima coincide with limestone intervals or strongly calcareous intervals at the majority of horizons, but in some cases, increases in strontium coincide with increased clay, quartz silt and sand, and a decrease in calcium carbonate (analyses were done on total rock crush).

It is not known if the strontium content in limestones is reduced upon dolomitisation by the same amount at each horizon. The groups of maxima (intervals F) in Grg 4 and 14 and 9A are of different orders, but the patterns are similar and occur at approximately the same height above datum level.

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Phosphorus (0-390ppm) content is generally low (10-50ppm) but a pattern of minima separated by a maximum occurs in similar positions in the three core holes. The patterns above and below these do not coincide, but individual peaks occur at certain horizons in each core hole.

Calcilog; the carbonates were analysed to obtain the general ratio of calcium carbonate to total carbonate by calcimetry before they were analysed for the trace elements. The semi-quantitative results were generally complimentary to the insoluble residue percentages and therefore the samples were not re-analysed for calcium/magnesium ratios.

For calcimetry, slices of core perpendicular to bedding were crushed to a grain-size of 0.012 - 0.024 inches; a sample of 0.25 grams was dissolved in cold hydrochloric acid (10%), and the amount of carbon dioxide lost after one minute and nine minutes was measured; after correction for room temperature and pressure, the total carbonate value was added to the insoluble residue percentage and the two values were generally complimentary. A sum differing from 100% resulted in some cases; this was probably due to different methods in calculating the amount of effervescing carbon dioxide and insoluble residue, the lack of correction data for temperature and pressure inside the flask, and the incomplete reaction after nine minutes. The dolomites were previously etched and stained (Warne, 1962) and the estimation for calcite was similar to that recorded by the calcimeter.

Calcium carbonate is low in amount and generally varies from 0-15% in Grg4, 0-5% in Grg 14, and 0-20% in Grg 9A. Interbeds of limestone occur in Grg 4 and are recorded clearly on the calcilog by peaks of 75-95%; limestone does not occur in the other core holes, and the calcium carbonate content does not exceed 15% in Grg 14, or 20% in Grg 9A.

The total carbonate content generally reflects the calcium carbonate curve but with greater ranges. The total carbonate percentage probably represents the percentage of dolomite in the sequence as no other carbonates were found.

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Environment.

Different types of dolomite form the sequence in each core hole; highly argillaceous and silty dolomites only occur in Grg 4; thin quartz sandstone beds occur infrequently in Grg 14 and 9A.

Microcrystalline to medium-crystalline dolomites predominate and are interbedded with dolarenites and dolorudites, with and without clay, quartz sand and silt which range generally from 0-10% but in parts up to 35-45%.

The general environment is considered to be one of high temperatures and salinity, with areas of low energy and high energy located over a shallow shelf. Deposition probably kept pace with slow subsidence; some areas were possibly above sea level at times, as the dolomite seems to be a result of penecontemporaneous alteration.

There is a noticeable decrease in the amounts of trace elements from west to east, from Grg 4 through Grg 14 to Grg 9A; this parallels a marked decrease in the amount of insoluble residue and limestone. These changes may reflect increasing distance across the region of carbonate deposition from a near-shore environment (Grg 4) to more open sea environment (Grg 14 and 9A). The area of deposition lay between land areas represented by the present Davenport Ranges in the west and the Standish Ranges in the east. These areas supplied small amounts of detritus to the area of carbonate deposition and the greater abundance of trace elements and insoluble material in Grg 4 suggest that it was located in a sequence nearer the old land mass than were the other core holes. Abundances of elements do not always coincide with abundances in clay minerals. In cases where there are high clay mineral and low element amounts, it is assumed that elements were not available in the source areas.

The distance from the shoreline and possibly changes in climate, for example storms, seem to account for the lateral decrease in abundance of all trace elements. Strontium is included in the above as it decreases with the increase of dolomite, and dolomite increases with distance from the shoreline both in this area and in other parts of the basin. The vertical distribution of elements varies with the availability of elements from the source area.

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Correlation.

The absence of fossils and the inconclusive correlation by sedimentary parameters (Nichols and Fehr, 1964; Nichols, 1966), stimulated an attempt to correlate by trace element distribution. Data on this kind of correlation is not widespread in the literature and the feasibility of the method has not been demonstrated fully. Although Turekian (1963, p.15) is doubtful of trace elements being useful in correlation in place of normal geologic criteria, they are here used to support the tentative correlations by sediment parameters (fig. 8).

In the present case, the correlations (fig. 6) are also tentative but certain intervals in each core hole are similar. The intervals of comparison contain groups of maximum and minimum amounts and certain individual peaks above and below these groups also occur and can be correlated. For example, the following intervals are tentatively correlated by groups of peaks or individual peaks of the various elements.

Nickel

Interval A in Grg 4, 14 and 9A.
Interval B in Grg 4, 14 and 9A.

Zinc.

Interval C in Grg 14 and 9A.
Interval D in Grg 4 and 14.
Interval E in Grg 4 and 14.
Peaks 1, 2 in Grg 4 and 14.

Strontium

Interval F in Grg 4, 14 and 9A.

Phosphorus

Interval G in Grg 4, 14 and 9A.
Interval H in Grg 4 and 14.
Interval I in Grg 4 and 14.
Peaks 3, 4, 5, in Grg 4, 14 and 9A.
Peaks 6, 7, 8 in Grg 4 and 14.

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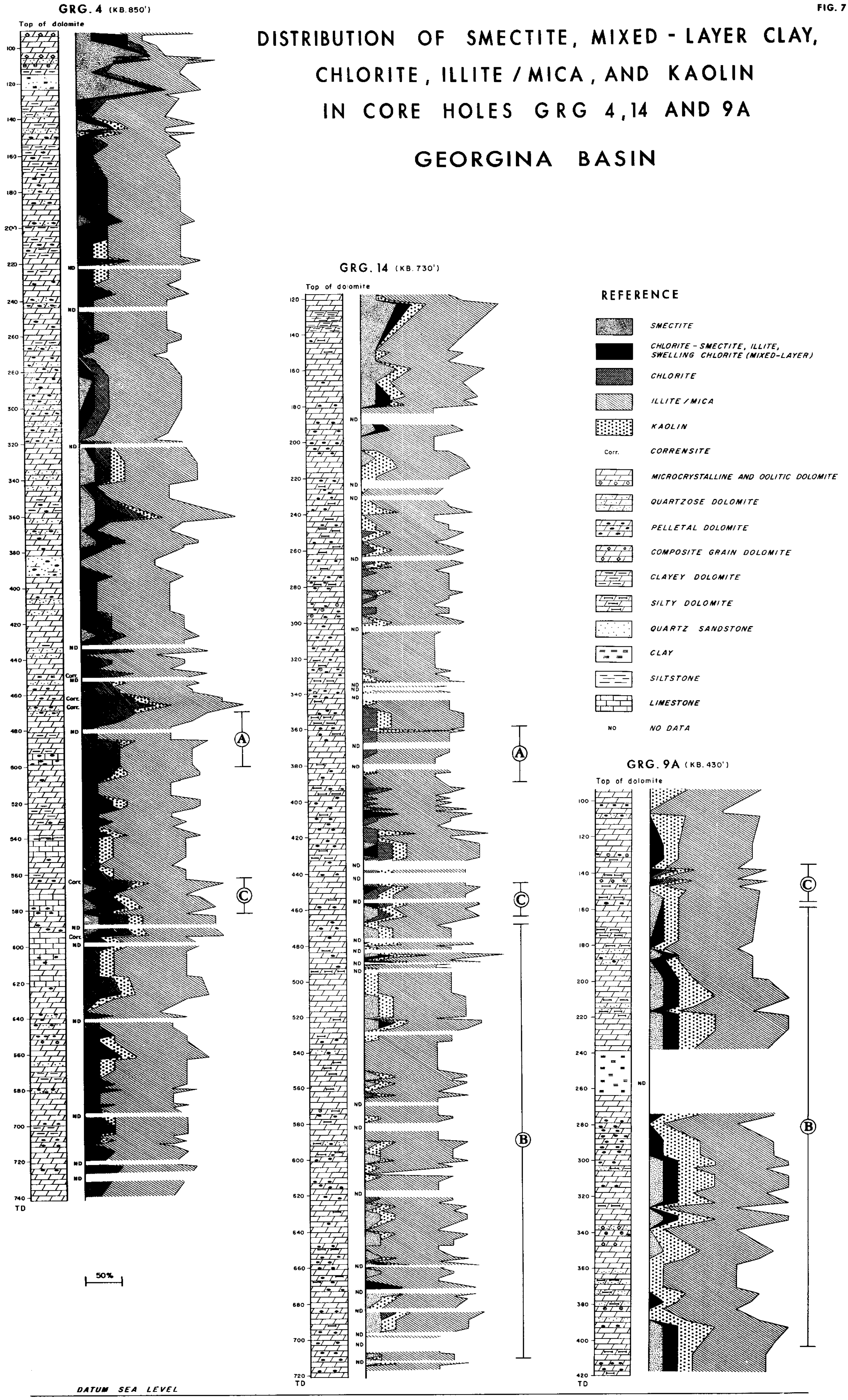
FIG. 7

# DISTRIBUTION OF SMECTITE, MIXED - LAYER CLAY, CHLORITE, ILLITE / MICA, AND KAOLIN IN CORE HOLES GRG 4,14 AND 9A

## GEORGINA BASIN

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The above correlations also delimit intervening areas which have nothing in common. This makes the comparison suspect unless it can be argued that environmental changes at the intervening times were localised and therefore precluded any similarity across the area.

Turekian (1963, p.15) argued that the differences in abundance of elements in the Florena Shale, and by inference in other rock units, made correlation by trace elements doubtful. In the present case it is argued that although the amounts of elements in each core hole are different, the recognition of similar distribution patterns may indicate comparable intervals.

Distribution of selected Clay Minerals in parts of the dolomite unit.

Introduction.

Samples from dolomite sequences, 400-750 feet thick, in core-holes Grg 4, 14 and 9A in the Georgina Basin which have been studied petrographically and analysed for Co, Ni, Pb, Zn, V, P, and Sr, were also analysed for smectites, mixed-layer clays (smectite-chlorite, smectite-illite), chlorite, illite/mica, and kaolin. These were plotted against the lithology log for each core-hole (fig. 7). The dolomite sequences examined are situated approximately 70 miles apart in an east-west line across the central part of the Georgina Basin, and approximately 35 miles from outcrops of Precambrian igneous and sedimentary rocks.

The clay minerals were identified semi-quantitatively by the Australian Mineral Development Laboratories (Stock and Trueman, 1966, p.1), following a request by the Bureau of Mineral Resources for analysis of the samples for illite, montmorillonite, kaolinite, corrensite and attapulgite. The request for these five clays was stimulated by a report (La Compagnie Francaise des Petroles, 1963) which suggested they were useful for correlation between some sedimentary basins in Australia.

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Techniques.

The clay mineralogy was determined by X-ray diffraction using a diffractometer and cobalt radiation. Each acid insoluble residue was ground to minus 200 mesh and oriented on a ceramic specimen plate; the specimens were examined untreated and after saturation with glycerol. A third examination of most specimens after being treated at 500°C for 1.5 hours was necessary for complete identification of the clay minerals (Stock and Trueman, 1966, p. 2).

Clay mineral nomenclature.

The clay minerals in this report are used in accordance with the following definitions.

Smectites - 12-15A sheet silicates which swell with glycerol to approximately 17.7 to 18A. Smectite is the British term referring to the montmorillonite group of clay minerals, montmorillonite, nontronite, beidellite, saponite and hectorite. When heated to 550°C a smectite collapses to a 9.5 to 10A basal spacing.

Chlorite and chlorite-related minerals. Sheet silicates with 14 to 15A basal spacings. They include:

a. True (or sedimentary) chlorite which does not expand with glycerol. Its (001) peak intensity is enhanced (and that of the 7A(002) reflection weakened) depending mainly on iron contents, by heating at 550°C.

b. Swelling chlorite behaves in a similar manner to true chlorite but swells with glycerol to 16A(001) and 8A(002) probably because of degradation of the chlorite.

c. Corrensite is a regularly interstratified chlorite-swelling chlorite giving a well developed integral series of reflections, namely 29.8, 14.6, 9.6A untreated. When saturated with glycerol corrensite swells to give reflections at 31.7, 15.7, 10.6 and 7.8A.

d. Random chlorite - swelling chlorite behaves as for c. except that, in general, the basal reflections are non integral. The (001) spacings untreated and treated with glycerol are 14.6 and 15.7A respectively. Some glycerol treated specimens showed a development of a 7.8A peak and some of these gave a faint suggestion of a peak in the vicinity of 32A.

This mineral is most probably equivalent to that mineral described by La Compagnie Francaise des Petroles (1962) as "corrensite in which the interstratification is of the same nature (as true corrensite) but less well ordered."

Mixed-Layer Clay Minerals are interstratified clay minerals. Various mixtures have been identified in the samples. Two or three may occur together and the first mentioned mineral is the host for the other(s). No attempt has been made to estimate the proportions of each member in the mixture as the interstratified minerals are generally in amounts too small for the measuring procedure.

Illite/Mica is a non-specific term for mica-like clay minerals with approximately 10A basal spacing. Illites do not swell with flycerol and except for slight decreases in (001) spacings and diffraction intensities are unaffected by heating at $550^{\circ}C$.

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Kaolin is the group name for the 7A clay minerals kaolinite, dickite and nacrite. These minerals do not swell with glycerol. Kaolinite is completely destroyed by heating at 550°C but dickite is not.

As the (001) peak of kaolin (approximately 7.09A) and the (002) peak of chlorite (approximately 7.15A) are not resolved by the diffractometer the kaolin content had to be estimated from the (002) peak of kaolin (3.58A) which, in the main, is resolved from the (004) peak of chlorite (3.54A). However, in the specimens where the chlorite content is high and the kaolin content low, the presence of kaolin may not have been detected. Also some of those specimens which gave poor diffraction patterns may have contained kaolin but are reported as having none.

As clay minerals have variable crystallinity and particle sizes, only semi-quantitative measurements are possible. The clay mineral content is determined by measuring the areas under the (001) diffraction peaks (except for kaolin, as discussed), and making due allowances for the distribution of diffraction intensity (Stock and Trueman, 1966, p.2).

The semi-quantitative terminology used in the work is;

Dominant = greater than 50%

Subdominant = 20-50%

Accessory = less than 20%

Trace = less than 10%

On the logs (fig. 7) the amounts of each clay mineral are given the following values,

Dominant = 50-100%

Subdominant = 20-50%

Accessory)<br>Trace ) = 0-20%

and were plotted at the maximum of each range for purposes of clarity.

FIG. 8.

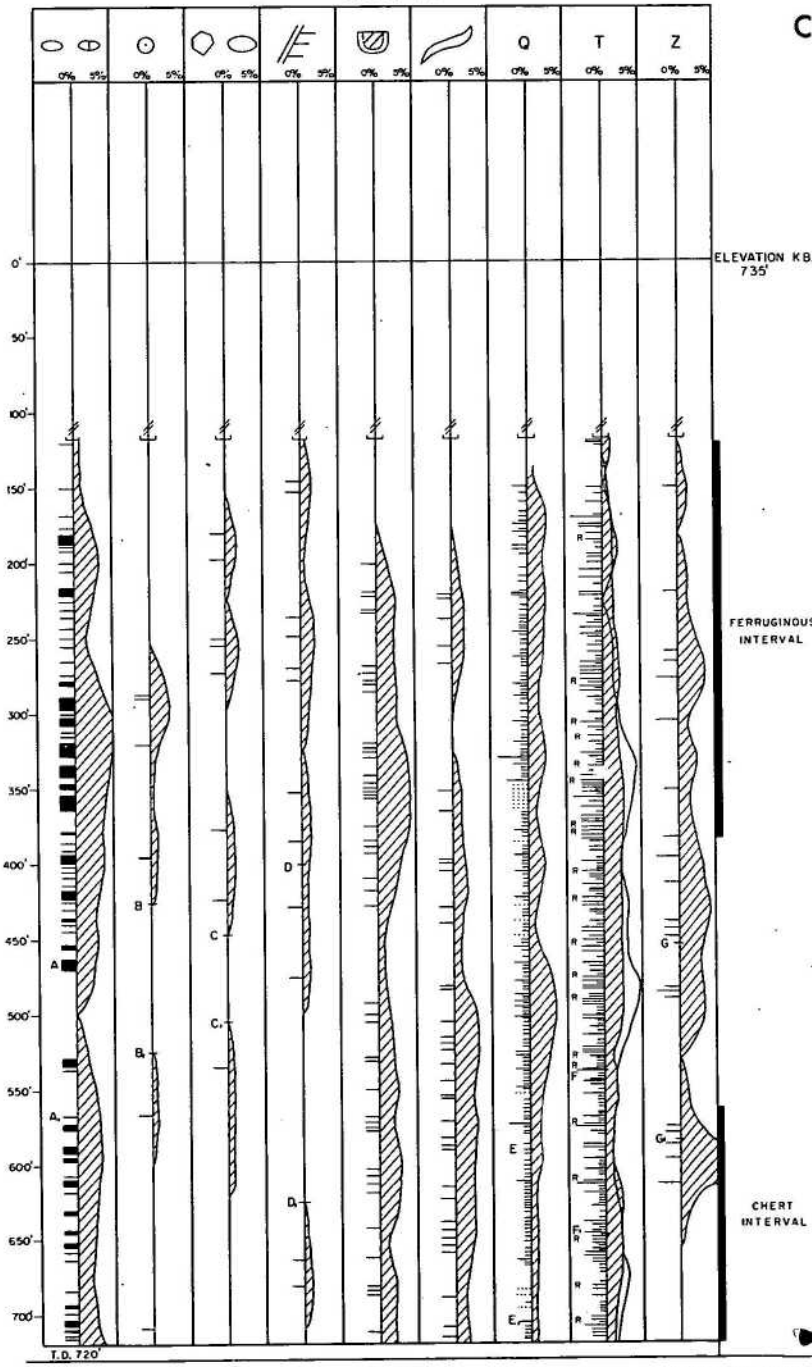
# CORRELATION LOG FOR GRG 14 AND GRG 9A

(Based on lithologic parameters)

## GEORGINA BASIN N.T.

(DATUM SEA LEVEL)

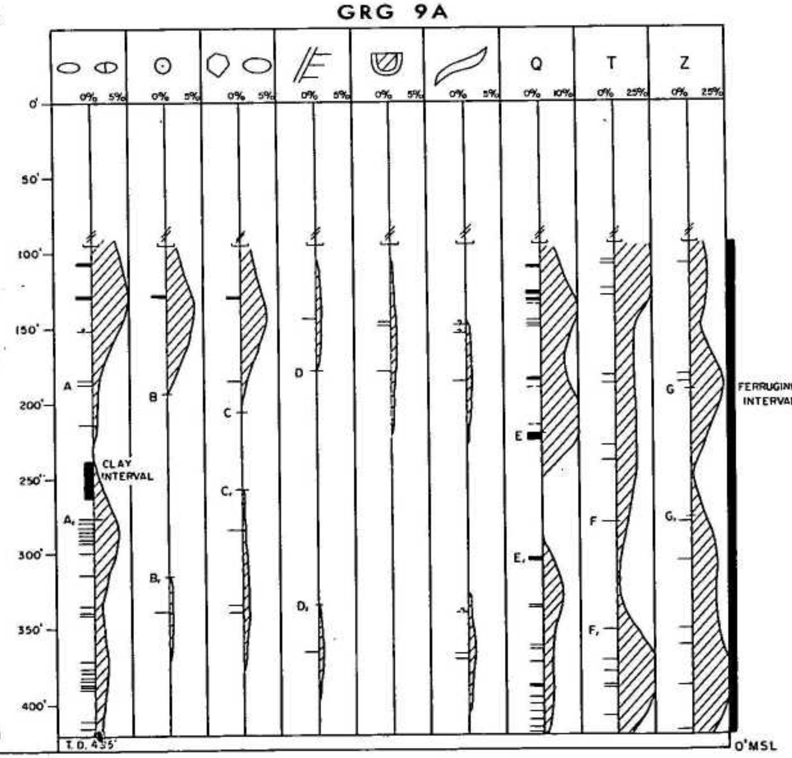
GRG 14




### REFERENCE

| | | | |
|---|---|---|---|
| | *Superficial deposits* | T | *Tourmaline (total)* |
| | *Pellets and intraclasts* | R | *Tourmaline (rounded detrital)* |
| | *Ooliths* | Z | *Zircon* |
| | *Breccia and conglomerates* | | *Sample point* |
| | *Cross bedding* | | *Occurrence* |
| | *Scour and fill* | | *Medium abundance* |
| | *Stumping* | | *Abundant* |
| Q | *Quartz sand (detrital)* | | *Frequency distribution curves per 50 feet with 50% overlap* |
| .... | *Quartz silt (detrital)* | | *Frequency distribution curve for rounded tourmaline* |

GRG 9A




*Bureau of Mineral Resources, Geology and Geophysics. January 1966. To accompany Record 1966/145*

F 54/A5/2

Distribution in the core-holes.

Smectite occurs in three wide intervals in Grg 4, but predominates in the upper half, while it forms thinner intervals in Grg 14, but predominates in the lower half, and forms wider intervals in Grg 9A almost throughout the sequence. The abundance is almost the same (0-20%) in each core-hole except for the upper parts of Grg 4 and 14 which contain more (20-50%) than elsewhere.

Mixed-layer clays occur frequently at intervals throughout Grg 4, rarely in Grg 14 and almost continuously throughout Grg 9A. The abundance is almost the same (0-20%) in each core-hole, except for rare intervals (20-50%) in Grg 4.

Chlorite occurs almost throughout Grg 4, is confined to thin intervals in the middle and upper parts of Grg 14 with rare intervals in the lower half, and occurs in one thin interval in Grg 9A. The abundance is high (20-50%) in some parts of the lower half of Grg 4, and low (0-20%) in Grg 14 and 9A.

Kaolin occurs rarely in the upper half of Grg 4, but is present throughout most of the lower half; it occurs sporadically throughout Grg 14 and in almost every sample in Grg 9A. The abundance is the same (0-20%) in Grg 4 and 14 but often greater (20-50%) in Grg 9A.

Illite/Mica occurs throughout each core-hole; six samples gave poor diffraction patterns in Grg 4; one interval contained none in Grg 14. The abundance is always high (50-100%).

Environmental relationship of the clay minerals.

The three core-holes are situated between Precambrian rocks to the east and west of the Georgina Basin. Grg 4 is at present 35 miles east of siliceous quartz sandstone, minor basic lava, gabbro, dolerite and rare granite in the Davenport Ranges (Smith, Stewart and Smith, 1961, p. 10). Grg 14 is 65 miles further east in the middle of the basin, while Grg 9A (75 miles south-east of Grg 14) is at present 35 miles west of basic volcanics and granite rocks (Carter, Brooks and Walker, 1961, p. 42) which form part of the north-eastern boundary of the basin.

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Weaver (1958, p. 171) states that clay minerals can occur in abundance in any of the major depositional environments and there is no consistent coincidence between specific clay minerals and specific depositional environments. He concludes that a great many clay minerals in sedimentary rocks are detrital in origin, and that they strongly reflect the character of the source material and are only slightly modified in their depositional environment.

Smectite, derived generally from the weathering of basic rocks (Deer, Howie and Zussman, 1962, p. 241), occurs more frequently in Grg 14 and 9A than in Grg 4 which is probably due to there being a great amount of basalt and some dolerite east of Grg 9A (Carter, Brooks and Walker, 1961, pp. 42-44), whereas only small amounts of basic rocks crop out west of Grg 4 (Smith, Stewart and Smith, 1961, p. 10). Appreciable quantities of smectite were probably not derived from reaction between magnesium and silica of silicified dolomitic rocks (Deer, Howie and Zussman, 1962, p. 241), as siliceous dolomites rarely occur in the sequence.

Mixed-layer clays (smectite-illite, smectite-chlorite) are derived from non-micaceous material (Deer, Howie and Zussman, 1962, p. 241) and occur frequently in Grg 4 and 9A in the western and eastern sides of the basin, but rarely in Grg 14 in the centre of the basin; they are more persistent in Grg 9A indicating a more continuous supply, possibly as there is more non-micaceous material in the east than the west and more basic volcanic rock. This distribution is in contrast to that described by Millot, Lucas and Wey (1963, p. 401) where regular mixed-layer clays appear at a greater distance from the edge of the Triassic sedimentary basin of Jura.

Chlorite may be detrital or authigenic and is a product of alteration of ferro-magnesium minerals, a characteristic mineral of green schist facies in metamorphic rocks, and a product of weathering (Deer, Howie and Zussman, 1962, p. 153). Chloritic clay types may also develop from montmorillonitic material in a marine environment (Whitehouse and McCarter, 1958, p. 81). In the Georgina Basin, chlorite persists throughout Grg 4 and is abundant in some parts (20-50%), while

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if occurs sporadically only in the upper part of Grg 14, and at one thin interval in the upper half of Grg 9A. The reasons for the variable distribution are unknown; it may be concentrated in the west because lagoonal conditions prevailed, whereas more open marine conditions existed further east. Hayes, (1963, p. 420), described this condition in south-east Iowa, U.S.A. but in the Georgina Basin, the persistence of kaolin and its increase eastwards does not support this explanation. Chlorite may be ubiquitous in the west if there was a greater supply from schists, gabbros, colerites and granites than from similar rocks on the eastern side of the basin. In addition, more chlorite could occur if the western environment was more saline. This is thought likely as this is the only part of the sequences that revealed chlorite associated with corrensite, and both possibly formed by transformation from illite in a saline environment (Millot, Lucas and Wey, 1963, p. 403).

Kaolin is derived by alteration of feldspars, feldspathoids and other silicates, either hydrothermally or by weathering, usually of acid igneous rocks (Deer, Howie and Zussman, 1962, pp. 208-209). Kaolin occurs sporadically in Grg 4 and mostly in the lower half, more frequently throughout Grg 14, and is persistent and abundant throughout Grg 9A. This is probably due to the hinterland east of Grg 9A being predominantly granite and volcanic rocks, while the west of Grg 4 has few igneous rocks.

Illite may be derived from weathered feldspars and other silicates, or by diagenesis from alteration of other clay minerals (Deer, Howie and Zussman, 1962, p. 223). It is an abundant ubiquitous mineral in all core-holes, but only in Grg 14, in the centre of the basin, is it the sole clay mineral in some intervals. Illite may also form from montmorillonite or change to montmorillonite, but it is not known if this occurred in these dolomites. The uniform abundance as far as can be determined from a semi-quantitative study, and distribution, implies that its presence is not totally controlled by the type of hinterland or source area, and that much of it may have originated from alteration of other clay minerals.

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Correlation.

Petrographic and trace element studies have been made of the dolomite sequences in each core-hole and tentative correlations were proposed as the distribution of some parameters was similar in each sequence. It was thought that supporting evidence for the tentative correlation might be gained by a clay mineral study, but the logs (fig. 7) indicate that the selected clays are of little value in this area of dolomite. Only three small intervals appeared similar.

Intervals A in Grg 4 and 14 contain chlorite, some kaolin and illite, but no smectite or mixed-layer clays.

Intervals B in Grg 14 and 9A contain predominantly smectite, kaolin, variable mixed-layer clay presence, and illite, but little and no chlorite respectively.

Intervals C in Grg 4, 14 and 9A show a similarity in the presence and abundance of mixed-layer clay, chlorite, kaolin and illite, with a slightly variable distribution of smectite.

It is thought that the nature of eastern and western hinterlands, comprising such different amounts of granite and volcanic rocks, determined the distribution and abundance of the clay minerals. The results do not indicate a strong environmental control and tend to support Weaver's (1958, p.171) conclusions, that the clay minerals strongly reflect the character of the source material. An interesting result is the discovery and location of chlorite-corrensite intervals which suggest that more highly saline conditions pertained during the formation of certain units in Grg 4 than pertained during the formation of similar units further east in the basin.

## GEOLOGICAL HISTORY OF CARBONATE DEPOSITION

### Regional distribution of carbonates

Introduction.

The Georgina Basin is approximately 110,000 square miles in area and originally seems to have been a topographic depression, eroded into hills and valleys, and partly enclosed by ranges of Precambrian rocks. The present form of the Basin indicates that there were linkages with other areas to the south-east and to the north-west at either end of the Davenport Ranges.

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During Cambrian times, warm shallow water saturated with calcium carbonate transgressed over a folded and eroded surface of quartz sandstone in northern, central and eastern parts, and over folded eroded quartzite, and granite and rare gneiss in the western and southern parts of the basin.

This land surface was Precambrian in age (based on the age of the overlying rocks and the folded, unfossiliferous nature of the rocks forming it). In parts, the relief ranged over 1,000 feet though how abruptly is not known, and as the sea transgressed, carbonates of different ages overstepped onto the Precambrian basement. It is impossible to describe the environments of deposition in terms of stages as insufficient fossil control is available, therefore they are described from arbitrary intervals of lower, middle and upper parts of the succession; ages where known are added.

Lower units.

These are the first carbonate sediments to accumulate, and in many cases are the first sediments above the folded, quartz sandstone of the basement (fig. 9).

In the south-western part of the basin in the Huckitta area sedimentation was continuous from the Precambrian and in Lower Cambrian times quartz sand and silt were deposited. In some parts bioclastic carbonates accumulated containing brachiopods and archaeocyathids interbedded with algal and quartzose carbonates (Smith, 1964(b), p. 33). These carbonates are dolomites but the origin of the dolomite is unknown. North of this area on the southern and eastern side of the Davenport Ranges (Smith and Milligan, 1963, p. 6) and near Ooratippra (Lloyd and Bell, 1964, p. 16) quartz sand and silt were deposited on Precambrian folded quartzite, gneiss and granite, but were overlain by bioclastic and oolitic lime sands and carbonate mud (Newton, 1964).

In the northern part of the basin in the Brunette Downs areas calcite mud with few impurities was deposited over folded quartz sandstone (Papuan Apinaipi Petroleum Co. log, 1965) while the first sediments in the north-eastern parts, around Morstone were quartz sand and argillaceous

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calcite mud (Stewart and Hoyling, 1963, p.15). Some of the limestones are partly dolomitised.

In the more central parts of the region in the Avon Downs and Sandover River areas, carbonate mud, possibly with some organic material, accumulated (Johnson, Nichols and Bell, 1964, p.13). Intra-clastic lime sands with quartz sand and sandstone grains were deposited further south (Brown, 1965, p.6) and similar sediments formed in the Sandover River area (author's observation from Mulga No.1 well), all accumulating over folded quartz sandstone.

In the southern parts of the basin in the Tobermory area, silts and bioclastic lime sands accumulated in parts (Smith, 1965, p.7), while argillaceous and quartzose calcite mud and calcareous quartz sand were probably the first sediments deposited further north west (Nichols and Bell, 1965, p.10).

In the eastern parts of the basin in the Urandangi and Mount Isa areas, carbonate deposits accumulated possibly as muds (Noakes, Carter and Opik, 1959, p.9); Opik, Carter and Noakes, 1961, p.11). These were subsequently dolomitised; periodically quartz sand was deposited, and in other places silts and sands accumulated first followed by carbonates as the sea transgressed.

Some of the first carbonate sediments contain Lower Cambrian fossils and are here considered as part of the Georgina Basin sequence, although this is not widely accepted (Smith, 1964(b), p.59). Many contain Middle Cambrian fossils (some of which Russian palaeontologists place in the Lower Cambrian, A.A. Opik, pers.comm.), others however appear unfossiliferous which prevents a complete reconstruction of the environmental conditions at various times as the Cambrian sea gradually spread across the Georgina Basin.

Summary.

Broadly speaking, it seems that carbonate muds, partly argillaceous and quartzose, and rare carbonate sand accumulated under quiet conditions on an uneven Precambrian surface at different times during the Cambrian transgression. The hinterland and possibly islands provided quartz sand and silt at times, but erosion was not rapid as conglomerates are very rare.

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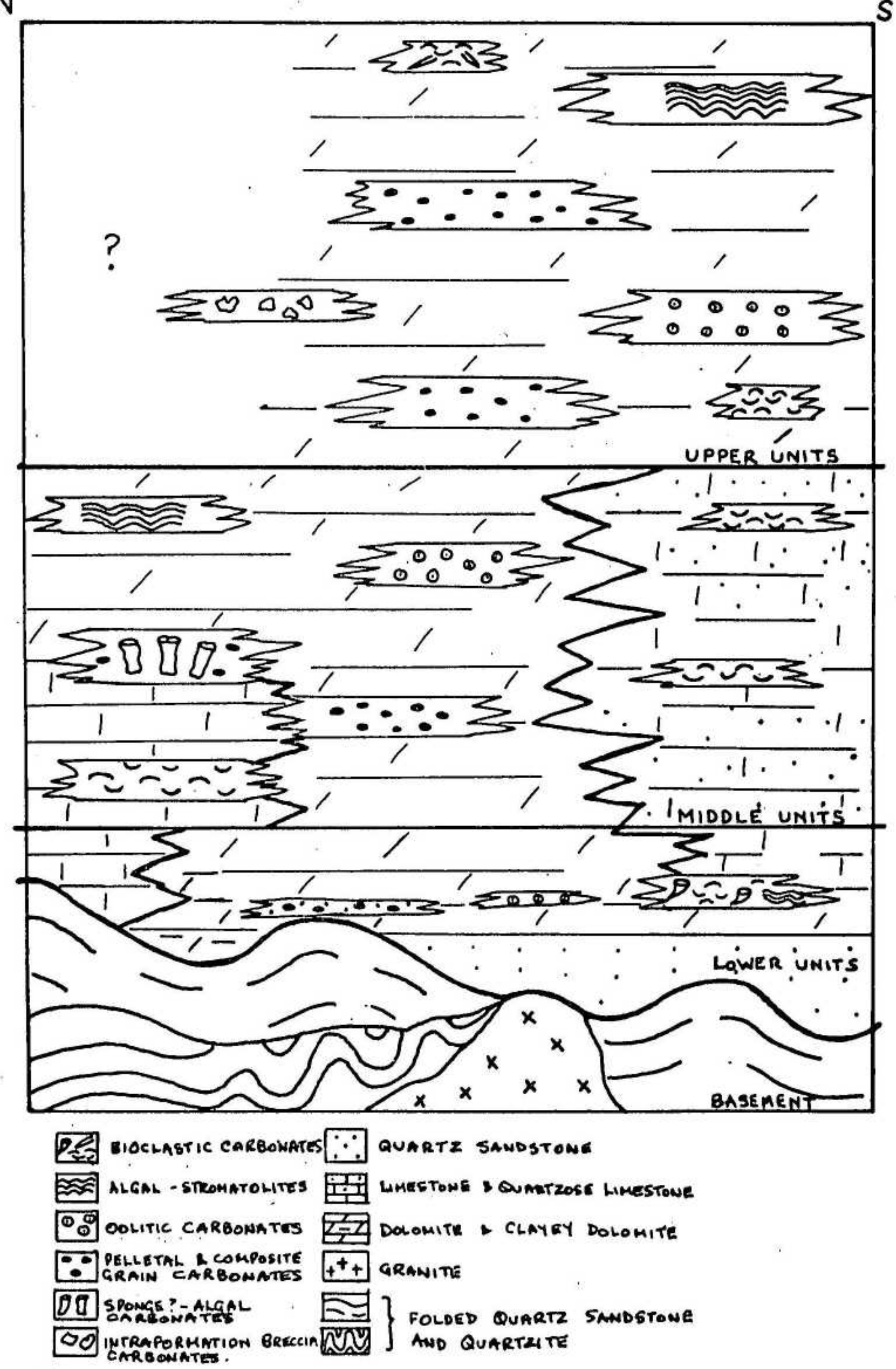
DIAGRAMMATIC RELATIONSHIP OF LIMESTONES AND DOLOMITES IN LOWER, MIDDLE AND UPPER UNITS, CENTRAL GEORGINA BASIN.



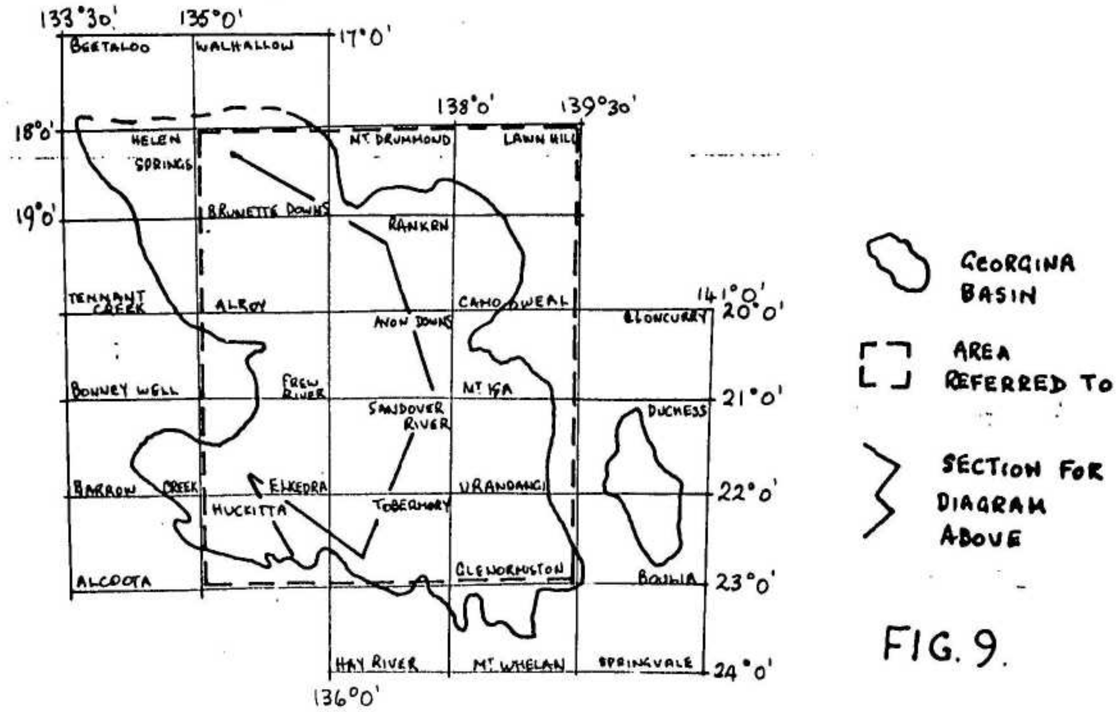




FIG. 9.

To accompany Record 1966/145

Periods of uplift and erosion possibly occurred during which some Lower Cambrian sediments were removed, prior to an apparently greater subsidence and transgression in later Cambrian times when many of the carbonate deposits accumulated and a carbonate province, about 90,000 square miles, developed.

Middle units.

These units overlie the lower units or earliest carbonate sediments, and are predominantly dolomites in a large part of the basin and limestones at the margins (fig. 9).

In the northern part of the basin in the Brunette Downs area, sponge(?) and algal formations grew amidst intraclastic and pelletal sands, calcite mud, and rare quartz silt and sand layers. The sponge(?) and algal formations possibly formed shallow patch reefs and were surrounded partly by calcite mud and partly by winnowed intraclastic carbonate sands. Fragments of trilobites and Echinodermata are scattered through the sediments, but bioclastic and oolitic deposits were rarely formed (Nichols, 1963, p. (i)).

The environment was predominantly shallow, calm and generally favourable for some organic growth and mud formation; in parts higher energy conditions prevailed around patch reefs and carbonate sands accumulated. Periodic uplift and possibly climatic change caused erosion and deposition of terrigenous sediment.

East of these deposits in the Ranken area, bioclastic lime sands and rudites of trilobites, hyolithids, brachiopod and echinoid fragments accumulated with pelletal and oolitic lime sands and muds. Rare silt and pebble conglomerates also formed (Randal and Brown, 1962(b), p. 8). Current action and possibly scavenging action were greater in this area and possibly shallow banks and shoals developed at different times in a very shallow sea; some shell banks may have been shoreline deposits (Opik, 1957(b), p. 41).

In the Camooweal area a large body of predominantly carbonate mud (Brown, 1962, p. 5) lay to the east of the bioclastic and oolitic deposits (it is largely microcrystalline to medium crystalline dolomite at present). In isolated areas, pellet sand and intraformational conglomerates formed (Randal and Brown, 1962(b), p. 5) and quartz sand was admixed. Stromatolite formations also grew in favourable zones and the whole environment was probably an extremely shallow one, possibly a mud bank area, partly exposed at low tide; this could account for the formation of stromatolites (Logan, Rezak and Ginsburg, 1964, p. 68) and the penecontemporary dolomite (Illing, Wells and Taylor, 1965, p. 89).

In the north-eastern part of the area around Morstone the earliest carbonate muds were overlain by pelletal, oolitic and algal carbonate sands with some bioclasts and quartz sand, deposited by strong currents sweeping across the area from the north-east (Randal and Brown, 1962(a), pp. 9-10). These currents changed direction on reaching the stromatolite and carbonate mud banks and began flowing south-eastwards, depositing similar carbonate sands. Large festoon beds formed partly against a reef front (cf. sea-cliff, Opik, 1957(a), p. 13) and partly interfingering with the carbonate mud (Randal and Brown, 1962(a), p. 7).

The strongly cross-bedded carbonate sands pass laterally and possibly vertically into lenses of calcite mud and layered pelletal and oolitic carbonate sands with some bioclasts (Brown, 1962, p. 9).

The carbonate mud banks or flats with pelletal sands which covered a large area of the northern parts of the basin extended southwards to the central part where the earliest carbonates were overlain by carbonate mud and pelletal, intraclastic and oolitic sands (Johnson, Nichols and Bell, 1964, pp. 12-13; Brown, 1965, p. 5) many of these are now dolomites but evidence of original calcite deposition may be inferred from the lack of differences between dolomite and limestone textures (Brown, 1965, p. 5).

Similar carbonate deposits accumulated in the south-central part of the Basin (author's observations of Mulga No. 1, 1965), and possibly further west where oolitic and microcrystalline carbonates were deposited (Smith, 1964(a), p. 9).

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In the south-western part of the basin, the environment did not change greatly and early bioclastic, algal and quartzose carbonates were succeeded by oolitic and bioclastic sands, algal and lithographic carbonates, in the Elkedra area (Smith and Milligan, 1963, p. 7) and by carbonate muds, some bioclastic carbonates with trilobites, brachiopods and hyolithids and quartz silt and sand which graded laterally into the carbonate deposits (Smith, 1964(b), p. 39).

Greater changes occurred in the southern and eastern parts of the region. The strongly quartzose, argillaceous, carbonate muds continued to form in the Tobermory area with some periods of quartz free mud formation (Nichols and Bell, 1965, p. 12). In the Urandangi area, quartz silt and sand and some conglomerates predominated with only minor carbonate deposits (Noakes, Carter and Opik, 1959, table 1), while in the Mt. Isa area impure quartzose, argillaceous and bituminous calcite muds formed, overlain by quartz sand and silt (Opik, Carter and Noakes, 1961, table 2).

Summary.

Thus during these times, (Middle Cambrian where the sediments can be dated) between 600-1,500 feet of carbonate sediments accumulated over the lower units and a large, dominantly carbonate complex was established with many lateral and vertical variations throughout the Georgina Basin.

The region was covered by shallow warm water with areas of high and low current strength and activity which controlled the locii of mud formation and the bioclastic, algal, oolitic and intraclastic accumulations. The northern and western areas were relatively stable shelf areas, while the southern part possibly subsided more rapidly, but deposition kept pace, and therefore shallow water conditions were maintained. Land erosion was also greater adjacent to this part of the Basin, and more quartz sand and silt and clays were mixed in the carbonate muds.

The eastern part of the basin, possibly divided into two areas (by the present Pilpah and Saint Smith Ranges), quartz sand, silt and rare, impure carbonates formed under shallow, near-shore conditions in the Urandangi to Mt. Isa area. The Morstone area was situated between

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land and the more stable carbonate mud and stromatolite banks; it was swept by strong currents at times and represented an area of more open circulation; precipitation of carbonate mud occurred periodically.

Upper units. (fig. 9).

There is no record of the continuation of deposition in the northern half of the Georgina Basin, and the upper units represent great thickness of carbonate units which overlie the middle units in the southern half of the basin. No major angular or erosional unconformities have been detected, but rare intraformational conglomerates and scour surfaces indicate periods of interrupted deposition.

In the south-west part of the basin in the Huckitta area, carbonate mud, oolitic lime sands and algal formations developed vertically and laterally and contained admixtures of quartz, sand and silt. At times, layers of quartz sand and silt spread across the area and thicker bodies accumulated (Smith, 1964(b), p. 43). Large colonial algae developed only in local areas (op. cit., plate 4). Bioclastic deposits rarely accumulated and only a few fossils of Upper Cambrian age apparently inhabited the area.

In the central and southern parts of the basin in the Sandover River and Tobermory areas, large thicknesses of similar carbonates were deposited, and oolitic, pelletal and probably intraclastic lime sands accumulated at different times alternating with calcite mud and stromatolite formations (Nichols and Fehr, 1964, p. 6; Nichols, 1965, p. 8; Smith, 1965, p. 8). Periodically, small amounts of ripple marked quartz sand and silt, and clay accumulated, and intra-formational breccias formed (Smith and Vine, 1960, p. 17; Milligan, 1963, p. 18), but no large quartz sand bodies persisted throughout the area. Some intraformational breccias contain large fragments of microcrystalline dolomite and angular chert in the Sandover River area (Nichols, 1965, p. 4) and this implies uplift, cementation and chert formation in older carbonates. As these do not exist in adjacent Precambrian rocks, they probably derive from earlier Cambrian deposits. The carbonate conglomerate beds indicate that areas were possibly above sea level, and it is postulated that dolomitisation occurred during these times.

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In the western parts of the basin, pelletal lime sand and muds accumulated, over 700 feet thick (Milligan, 1963, p.21).

Bioclastic lime sand and rudites rarely formed and only one or two scattered gastropods (of probably Upper Cambrian age - J.G. Tomlinson, B.M.R., pers. comm.) and nautiloids (of Lower Ordovician age, A.A. Opik, B.M.R., pers. comm.) were found. In contrast, there are many columna algae and layered-columna stromatolite formations, some of which extend for several miles (E.N. Milligan, B.M.R., pers.comm.), indicating the development of flat reef-like structures in shallow, sunlit, possibly intertidal waters (Logan, Rezak and Ginsburg, 1964, p.68).

Gradually, more than 2,500 feet of different types of carbonate sediment accumulated in these areas, whilst in the south-eastern part of the basin, sandy marl, silt and quartz sand were deposited with rare carbonate deposits in parts (Noakes, Carter and Opik, 1959, p.10; Condon, 1958, p.10), with carbonate muds, lime sands and algal colonies further south (Reynolds and Pritchard, 1964, p.3).

These carbonates are the last record of carbonate sedimentation in the major part of the Georgina Basin, as subsequently, deposition was mainly in the form of quartz sand, in the south-western part, and carbonates appear to have been restricted to the south-eastern part; the change in environment occurred at some time in the Upper Cambrian.

<u>Summary</u>.

Upper units are preserved only in the southern part of the basin, indicating carbonate deposition continued in parts, while the few fossils found range from Middle Cambrian to Lower Ordovician, though fossils of the latter age are restricted to the south-eastern section of the basin. Carbonate deposits forming the middle units of the sequence were succeeded by a slightly different complex. The calcite muds, bioclastic, quartzose and rarely oolitic carbonates were overlain by a complex of pelletal, oolitic and intraclastic lime sands, calcite mud and algal-stromatolite formations. These possibly formed banks, shoals and reefs in a shifting environment for they succeed each other vertically and laterally.

Intraformational conglomerates occur, indicating periods of erosion and possibly emergence, and in many cases the carbonates are dolomites but the textures and grade sizes of the carbonate mud, ooliths and algal-stromatolites for example, are well preserved. The occurrence of the stromatolites has been recorded by authors in the present day from intertidal areas in Shark Bay, Western Australia, and some similar textural features in dolomites by various authors working in the Persian Gulf, Netherlands Antilles and the Bahamas.

In view of these facts, it seems that many parts of the Georgina Basin carbonate province were exposed periodically either by tidal variation or slight eustatic changes in sea level.

It is difficult to determine whether the great thickness of carbonates in the southern part of the basin is due to preservation by folding and faulting, or by greater subsidence than in the northern half. In no case is it possible to determine changes in thickness within a given stage throughout the basin because neither the fossils nor deposits of a known age are ubiquitous.

The increase in depth to the folded basement, from an average of 1,500 feet in the north to between 3,000 feet and 6,000 feet in the south may be a result of original erosion, syngenetic faulting or downwarping, subsequent folding and faulting or a combination of these factors. If downwarping occurred, the depositional rate kept pace and shallow water conditions were maintained.

## CONCLUSIONS

1. Rock units preserved in the Georgina Basin are predominantly carbonates which exhibit a large number of facies and form a sequence approximately 5,000 feet thick in parts.

2. The carbonates are here considered to range in age from Lower Cambrian to Lower Ordovician; some carbonates have been subdivided into beds and formations on lithological grounds, for example, the Marqua Beds, and some on the occurrence of fossils of different ages in

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the sequence, for example, Camooweal Dolomite, Meeta Beds and Ninmaroo Formation, and Arthur Creek Beds, Arrinthrunga Formation and Ninmaroo Formation.

3. The carbonates are varieties of limestone and dolomite, and comprise such units as microcrystalline (mud), algal, algal-stromatolite, bioclastic, pelletal, oolitic, composite-grain and intraformational breccia. Some are quartzose and argillaceous; quartz sandstone and siltstone form very thin interbeds. In some cases, the carbonate units possibly formed shoals and flat patch reefs.

4. The amount and distribution of Co, Ni, Pb, Zn, V, P, and Sr varies with the amount of insoluble residue and dolomite, and decreases with distance away from the ancient shoreline.

5. The distribution of the clay minerals, smectites, mixed-layer clays, chlorite, Kaolin and illite/mica is controlled by their availability in the source areas and seem unaffected by environment of deposition. The distribution of chlorite and corrensite in Grg 4 may delineate intervals of high salinity in the sequence.

6. At the close of Precambrian time the Georgina Basin was essentially a region of folded and eroded Precambrian quartzites, granites and quartz sandstone, except in the south-western part where deposition continued from the Precambrian, and bioclastic and algal carbonates of Lower Cambrian age accumulated over quartz silt and clays.

7. As subsidence continued carbonate muds and rare carbonate sands accumulated and overstepped onto Precambrian rocks in some parts, while quartz sand, silt and thin carbonates formed in other parts. The ages of the oversteps are unknown as fossils have not always been found in the lowest deposits. In the remainder of the basin the first bioclastic deposits found at some thickness above the basement are of Middle Cambrian age.

8. A large carbonate province had developed in the region by Middle Cambrian time and a complex of environments was established over a predominantly shelf-like area covered by shallow, carbonate-

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rich, often highly saline water, by analogy with conditions under which similar deposits are forming today.

The environments varied vertically and laterally from those of high energy, possibly unprotected and organic-rich with bioclastic lime sands and rudites, to more chemical environments of high energy, inimical to organic life, with oolitic, pelletal and composite-grain lime sands, and those of low energy, possibly protected, with partly quartzose lime muds. Some of these areas were possibly intertidal or above sea level at times when some algal stromatolites formed and when penecontemporaneous dolomitization probably occurred, mainly in the northern and central parts.

9. As deposition continued into Upper Cambrian times, similar environments persisted in the central part of the basin and developed in the southern part. The complex of oolitic, pelletal and composite-grain lime sands interbedded with calcite mud and algal stromatolites continued to develop in the central parts and began to accumulate in the southern parts overlying the quartzose carbonate muds and slightly bioclastic deposits. Periodically, thin ripple-marked quartz sand were deposited.

Some parts were again partly intertidal at times, and provided material for intraformational conglomerates and were penecontemporaneously dolomitized; algal stromatolites also developed at these times. Most of these conditions seem to have been inimical to animal life and only the algae appear to have flourished.

10. Towards the end of this period (Upper Cambrian to Lower Ordovician) large quantities of quartz sand and silt were swept across the southern parts of the area and deposited to the west of a greatly reduced carbonate province.

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