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TITLE: EXPLANATORY NOTES ON THE ESPERANCE-MONDRAIN ISLAND 1:250,000 GEOLOGICAL SHEET, WESTERN AUSTRALIA

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CONTENTS

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LIST OF MAPS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The Esperance (SI/51-6) and the Mondrain Island (SI/51-10) 1:250,000 Sheets were mapped between 1965 and 1967 in conjunction with a hydrogeological investigation of the Esperance Sand Plain.

Apart from isolated granite hills and low sand dunes, the land surface is very flat and rises from sea level, through a series of poorly defined sloping benches, to a height of about 500 feet above sea level. A small coastal plain is developed in Esperance Bay and this is backed by a low escarpment about 150 feet in height.

The coast is strongly indented with numerous rugged rock headlands, and Cape Le Grand, a prominent feature in the area, rises to a height of over 1,100 feet. Offshore numerous small, steep, rocky islands and reefs, which form part of the Archipelago of the Recherche, extend for some 40 miles to the edge of the continental shelf. The shelf, which is characterized by a number of platform and valley features, ends rather abruptly at 55 fathoms (330 feet) where it joins a dissected continental slope.

River drainages are only well developed along the coast, where steep gorges and river terraces show signs of terminated rejuvenation. In the western part of the Sheet area, known as the Esperance land district, drainages extend inland on the plateau as a chain of small, interconnected salt lakes. In the eastern part, which is known as the Neridup land district, channels end abruptly on the plateau at about 250 feet above sea level. The Neridup district is generally flatter and lower than the Esperance district.

The plateau is covered by numerous small clay pans. In the northern half of the Sheet area the clay pans are saline, elongated, and show a north-northwesterly migration.

In the south the clay pans are static, rounded, and give rise to semi-permanent, fresh water swamps.

The annual rainfall decreases from approximately 30 inches on the coast to a less reliable 15 inches about 40 miles inland. Climatic averages for Esperance are shown in Table 1.

Previous work on the area is described by Fairbridge and others (1954), Clarke and others (1954), and Berliat (1952), but prior to the work recorded in this report, no comprehensive geological investigation had been attempted. The attached geological map was compiled by K.H. Morgan, under the supervision of R.C. Horwitz. C.C. Sanders assisted in mapping the Archipelago of the Recherche (Morgan and others, 1968). The descriptions of the Proterozoic rocks in these notes are by Miss R. Peers.

PRECAMBRIAN GEOLOGY

INTRODUCTION

Proterozoic rocks of the Esperance-Mondrain Island sheet area underlie almost all the mainland area and also form the offshore islands. Southward extrapolation of the geology of the Norseman sheet area suggests that Archaean granite may underlie the northwestern corner of this sheet (Fig.1), but the area has no surface exposure. The Proterozoic rocks may be subdivided into three units, the gneissic migmatite, the granite and the migmatite. The gneissic migmatite of the western quarter of the sheet represents a pile of geosynclinal sediments which have been metamorphosed to a general level of almandine-amphibolite facies grade by regional metamorphism. Individual bands have been more highly metamorphosed to granulite facies grade. The intrusion of the granite in the east of the sheet produced a zone of migmatite between the granite and the gneissic migmatite.

Gneissic Migmatite

The gneissic migmatite unit underlies the western quarter of the Esperance-Mondrain Island 1:250,000 sheet area. It is poorly exposed except for local outcrops along the Dalyup River, and the excellent exposures at Eleven Mile Beach, Butty Harbour and Butty Head.

The coastal exposures extend as platforms across the strand line into the ocean, and are strongly banded and steeply dipping. There is extreme lithological variation from band to band in this unit; the rock types including granite, amphibolite, augen gneiss, pegmatite and metamorphosed dolerite. The intimate mixture of these contrasting rock types with such striking colour variation is the reason for the local name "Pudding Rocks" at Butty Harbour. Some bands are intensely folded but the degree of deformation varies from band to band and is a reflection of the initial variation in competency of the layers. The variation in lithology between adjacent broad bands of this metasedimentary unit is probably a reflection of primary sedimentary layering, but the small-scale layering and pegmatite bands are almost certainly due to metamorphic differentiation. Basic dykes and sills were intruded prior to metamorphism.

The predominant rock type of this unit is an augen gneiss in which the dark bands are studded with red garnet and the light bands by "augen" of feldspar. All hand specimens are characterized by an alternation of light and dark bands, although the definitions of banding, grain size, and mineral content are variable.

The gneissic migmatite at Eleven Mile Beach is represented by a medium to coarse-grained garnetiferous gneiss with bands of pegmatite. The light bands of the gneiss are composed of quartz, microperthitic microcline and minor plagioclase with marginal myrmekite. Biotite predominates within the dark bands and is pleochroic with X = straw, Y = orange, and Z = dark reddish brown. Other minerals include pink garnet and irregular porphyroblasts of orthopyroxene which are pleochroic from pale pink to pale green. Accessory minerals include euhedral apatites, zircons, fresh black opaque grains, and metamict allanite grains. Alteration products include chlorite after biotite, carbonate, and clinozoisite. The presence of fractured garnet and pyroxene grains, and the curved twin planes of the plagioclase are evidence of the deformed nature of these rocks.

A selection of the various rock types of the gneissic migmatite was collected at Butty Harbour (Pudding Rocks). These include gneisses rich in biotite or biotite and amphibole, and metamorphosed dolerite. The gneissic bands are largely composed of strained and fractured quartz grains, oligoclase (which is sometimes antiperthitic) with curved twin planes, and marginal myrmekite. Some specimens include lightly kaolinized, microperthitic microcline. The amphibole which occurs in these gneisses is strongly pleochroic with X = pale green, Y = olive green and Z = dark green. Minor alteration to chlorite and green biotite is common. The biotite is pleochroic with X = pale yellow, Y = greenish brown, and Z = dark brown. Accessory minerals include apatite, pink garnet, fresh opaque grains rimmed by sphene, rare pyrite and metamict allanite grains.

One specimen of higher grade gneiss includes a plagioclase of composition An_{40} (andesine) and grains of orthopyroxene altering to amphibole.

The metamorphosed dolerite sampled at Butty Harbour is an unusual rock composed of clastic fragments of clinopyroxene with biotite, quartz and plagioclase. The average grain size of the pyroxene is 0.3 mm. Shearing stress has destroyed the original texture and mineralogy. The pyroxene grains and biotite flakes are oriented parallel to the foliation. Accessory minerals include apatite and pyrite.

A pegmatite from an outcrop in the Dalyup Creek is the only other rock type recorded from the gneissic migmatite. It is coarse grained and composed of quartz, sericitized plagioclase and kaolinized microcline.

Granite

The granite of the sheet area underlies the eastern half of the region. It is well exposed as small inliers such as Mount Marion, 12 miles east of Esperance and inland from the coast, and at Wylie Head about 5 miles east of Esperance. The outcrops are typical of granite, being well rounded and smooth with exfoliation flakes and piles of granite tors. Lower, rounded "pavement" type outcrops are commonly covered by a consistent layer of lichen making the collection of fresh specimens difficult.

The typical granite is a medium to coarse grained pink and pale grey rock crammed with microcline phenocrysts showing simple twinning and having a strong flow lineation, and abundant black biotite. The granite is not altogether homogeneous as coarse pegmatitic patches and biotite-rich schlieren were noted at Wylie Head. The predominant minerals are microcline, plagioclase, quartz and biotite. Microcline phenocrysts show normal multiple twinning but are also twinned on the Carlsbad law. They are lath-shaped crystals up to 3 cm long. Otherwise microcline forms anhedral grains, which are microperthitic but also includes coarse grains of plagioclase and quartz. Alteration is limited to light kaolinization. Plagioclase is the subordinate feldspar and forms anhedral grains which are well twinned on albite, Carlsbad and pericline laws. It was identified as oligoclase (An_{25}) and includes irregular patches of potash-feldspar (microcline) in an antiperthitic texture. Some of the plagioclase grains have well developed myrmekite along the margins adjacent to microcline. Minor alteration to sericite and carbonate has occurred. Quartz forms large anhedral grains with moderate strain extinction, numerous two-phase inclusions along annealed fracture surfaces, and included zircons. Quartz also forms myrmekite with plagioclase. Flakes of biotite are commonly clustered and are strongly pleochroic with X = pale yellow, Y = greenish brown, and Z = brown. They include apatite, zircons rimmed by pleochroic haloes, and opaque grains. Muscovite flakes are sometimes associated with the biotite. Accessory minerals in the granites include euhedral and subhedral apatite grains, zircon, fresh black opaque grains, and more rarely irregular grains of sphene. Not all of the granite is rich in biotite. Some of the granite shows signs of stress, with fractured grains, curved twin-planes in the feldspars, and larger grains rimmed by crushed grains.

The biotite-rich schlieren sampled at Wylie Head are similar to the typical granite in composition and texture except for a higher content of biotite. Pegmatite sampled at the same locality is a coarse-grained aggregate of fresh microcline and quartz with plagioclase and minor biotite.

Migmatite

The migmatite unit of the Esperance-Mondrain Island 1:250,000 sheet is a mixture of the intruded granite and the gneissic country rock represented now by the unit gneissic migmatite. As with the other Proterozoic units, the migmatite is best exposed along the coast where smooth, curved outcrops form headlands which plunge into the ocean. The rock is very broadly but distinctly banded in a mixture of dark and light rock of varying grain sizes. Much of the paleosome is biotite and amphibole rich. Pegmatoid leucoxenes occur as veins and clots and those sampled at Taylor Boat Harbour include clots of ilmenite. At some localities, such as Rossiter Bay, the paleosome and neosome are not readily distinguishable at close quarters, the structures being best viewed at a distance. This migmatite may be classified as having a "nebulitic" structure (Mehnert, 1968). In a small bay south of Frenchman's Peak, on Cape le Grande, amphibole-bearing paleosome material has formed well developed boudins.

The metamorphic phase of this migmatite is a granitic gneiss. At Taylor Boat Harbour, augen of feldspar are included, and throughout the unit there are bands rich in biotite and/or amphibole.

The predominant minerals are quartz, microcline and plagioclase, with biotite and accessory minerals. Quartz forms anhedral grains with mild strain extinction and abundant two-phase inclusions. The microcline grains are well twinned anhedral grains which are microperthitic and quite unaltered. Plagioclase is the subordinate feldspar forming poorly twinned, weakly zoned oligoclase grains. It is unaltered but commonly has developed marginal myrmekite. Biotite occurs as flakes oriented parallel to the foliation. It is pleochroic with X = pale yellow, Y = brown and Z = very dark brown. Pleochroic haloes rim inclusions of zircon. Accessory minerals include zircons and fresh black, opaque grains. Accessory sphene and apatite are not always present.

Some specimens include ragged laths of amphibole which are strongly pleochroic with X = green, Y = olive green, and Z = dark green. Commonly the co-existing biotite is redder than the biotite in specimens lacking amphibole. A specimen collected from the quarry at Coramup Hill includes broken grains of pink garnet associated with red biotite.

The mafic paleosome layers are characterized by an abundance of biotite, or biotite and amphibole and the predominance of plagioclase over microcline. The biotite-rich layers are composed of well twinned plagioclase (oligoclase-andesine), microcline, quartz and aligned flakes of biotite which are pleochroic with X = pale yellow, Y = yellowish brown, and Z = dark reddish brown. Rarely the biotite is more olive green. In one specimen the biotite was altering to chlorite which included a trace of fluorite. Accessory minerals include fresh, black, opaque grains, large grains of yellow sphene and large anhedral grains of apatite.

The amphibole-rich layers are composed of fresh plagioclase (oligoclase-andesine), microperthitic microcline, quartz, amphibole and biotite. In some specimens the plagioclase is antiperthitic. The amphibole is pleochroic with X = pale green, Y = olive green, and Z = dark green. Typical biotite pleochroism is X = light brown, Y = orange brown, and Z = dark reddish brown. Accessory minerals include zircon and apatite but some specimens include abundant large grains of an opaque mineral rimmed by sphene, anhedral grains of yellow sphene, and anhedral grains of apatite.

The typical granite of the neosome phase of the migmatite is a medium-grained, dark pink, porphyritic biotite granite. The microcline phenocrysts are up to 3 cm long and impart a strong flow lineation to the rock. Some of the neosome phase of the migmatite is fine-grained, pale-grey, biotite granite with a saccharoidal fabric.

Quartz, microcline, plagioclase and biotite are the predominant minerals. Quartz forms anhedral, fractured grains with mild strain extinction and lines of two-phase inclusions. Microcline is the predominant feldspar and forms well twinned microperthitic grains which are fresh except for minor kaolinization. Plagioclase (oligoclase) occurs as well twinned anhedral grains which are coarsely myrmekitic and lightly sericitized. Biotite flakes are scattered throughout and are variously pleochroic with X = pale yellow or pale green, Y = olive green, brown or orange, and Z = brown, dark green or reddish brown. Sometimes the biotite is altered to chlorite with the associated development of epidote spindles within the chlorite. Accessory minerals include opaque grains altering to leucoxene, subhedral apatite grains and zoned zircons. Accessory minerals which are not always present include pyrite, sphene and metamict allanite grains.

The pegmatoid leucosomes of the migmatite unit are composed of a coarse-grained aggregate of quartz, microperthitic microcline and sericitized plagioclase, with traces of biotite, muscovite, opaque grains, zircons, amphibole and carbonate.

Summary of Precambrian Geological History

1. The deposition of a thick pile of geosynclinal sediments which were subsequently intruded by basic dykes and sills

2. A period of regional metamorphism in which the sediments were metamorphosed to a general level of almandine-amphibolite facies grade but in some areas as high as lower granulite facies grade. This gave rise to substantial metamorphic differentiation within this unit transforming it into a heterogeneous migmatite. The period of regional metamorphism may have been interrupted rather than having progressed as a single event, but occurred prior to the emplacement of the granite to the east of the sheet and was associated with intense folding and shearing. All these rocks are believed to have a Middle Proterozoic metamorphic age (Compston and Arriens, 1968)

3. the emplacement of the porphyritic granite with the concomitant development of a wide zone of migmatite along the contact with the gneissic migmatite.

CAINOZOIC GEOLOGY

Plantagenet Group and related rocks

Cockbain (1968) upgraded the term Plantagenet Beds to Plantagenet Group, and defined two new formations; the Werillup Formation (including Nanarup Limestone Member), and Pallinup Siltstone.

Werillup Formation. The Werillup Formation was defined on a sequence of dark coloured sandstone, siltstone, and lignite, near Albany, and has been correlated, by Cockbain (1968), with sections encountered in the lower part of several bores in the Neridup and Esperance districts. At Neridup and Esperance the section rests on fresh granite, and it is probably restricted to the deeper valleys in bedrock. A typical section is shown on Table 3 (G.S.W.A. Neridup No.21 Bore). In this area the formation has a maximum known thickness of 110 feet, and contains up to 75 feet of the equivalent highly fossiliferous Nanarup Limestone Member.

The age of the formation has been determined as Upper Eocene. The discovery of the larger foraminifer Asterocyclina sp., and Dasycladacean algae, Neomeris sp. and Larvaria sp., indicate shallow, warm water conditions (Cockbain, 1968).

The Werillup Formation is overlain by the Pallinup Siltstone through a transitional brown to buff silty sandstone bed.

Pallinup Siltstone. The Pallinup Siltstone is a light coloured, frequently banded siltstone and spongolite, which occurs close to the Pallinup River near Albany (Cockbain, 1968). These rocks used to be considered as typical Plantagenet Beds, and almost certainly have a continuous section between Albany and the Eucla Basin. In the Esperance-Neridup district there is a change of facies from a sponge-mollusc rich claystone-siltstone sequence along the coast, to an unfossiliferous claystone-siltstone-sandstone sequence further inland. The maximum thickness recorded was 117 feet, and this was encountered in G.S.W.A. Neridup Bore No.13.

The formation overlies either the Werillup Formation, or fresh granite, in the southern part of the region, but northwards it overlaps on to deeply weathered and oxidized bedrock.

The occurrence of the nautiloids *Aturia clarkei*, *Teichertia prora*, and *Cimomia felix*, suggests that an Upper Eocene age can be given to the formation (Cockbain, 1968).

Weathered bedrock. North of about latitude 33°30'S the Pallinup Siltstone overlies decomposed and highly weathered gneiss, migmatite, and granite, with the gneiss being the most susceptible of the three to deep weathering. This weathering is thought to have taken place before the deposition of the Pallinup Siltstone, which in turn is made up of oxidized material. In the northern part of the Sheet area, elevated land contains sections of leached bedrock overlain by greybilly. The leached rock is considered to be contemporaneous with the weathered rock underlying the Pallinup Siltstone, which is pre-Upper Eocene in age.

Early Tertiary palaeogeography and depositional environment

An ancient land surface of low relief and with deeply weathered rock existed prior to the Upper Eocene. At this time the Dundas Hills and Fraser Range formed a narrow divide between the northeast-flowing rivers and south-flowing rivers which passed through the Neridup district (Morgan, 1965).

A lowering of sea level stripped inland surfaces, exposed deeper zones of weathering, and rejuvenated drainages along the coast. The area along the present coastline and shelf was eroded to bedrock, and steep, short drainages with a rugged topography were developed. One drainage apparently entered the northeast side of Esperance Bay and flowed southwest past Figure of Eight Island and probably joined the old Dundas Hills and Fraser Range system. Another short drainage line probably formed the head of the submarine canyon, which is now located near Termination Island (Von der Borch, 1967).

An Upper Eocene transgression resulted in the deposition along steep valleys of fresh land debris and carbonates. This was probably accompanied by a considerable amount of submarine slumping. When the Upper Eocene sea reached the plateau at the head of the main rejuvenated topography (along a line just inland from the present coast), it progressed rapidly to form a wide embayment along the ancient river system in the Neridup district. At this time deposition of the Pallinup Siltstone started, and sponge life began to flourish. At the peak of the transgression, which at its maximum must have reached about 900 feet above the present sea level, the Upper Eocene sea appears to have extended inland almost to the Dundas Hills and covered the elevated bedrock platform on the western part of the Sheet area (see Figure 2). The hills probably formed a narrow peninsula in an embayment of the Eucla Basin.

Later sediments which were deposited in a shallow, wide, turbid, shelf sea, were probably mainly contributed to by windblown material, and the results of minor tidal action upon oxidized material derived from an arid, low coast.

Pleistocene or Younger Tertiary Sediments

A green to grey clay which is overlain by a hard, white, nodular limestone covered by red loam, occupies most of the low lying land in the northern part of the Sheet area. The white limestone is thought to be an indurated calcareous subsoil horizon, which has been exposed at the surface by deflation. "Grey-billy", overlying yellow to brown clay, occurs on low rises. The sides of the hills are covered by cemented lateritic pisolites, which are underlain at a shallow depth by hard bedrock.

Sand plain deposits (grey sand, lateritic pisolites, and yellow clay). Yellow clay, overlain by lateritic pisolites and grey sand, occupies the central part of the plateau at a height of between 250 and about 400 feet. The area is generally referred to by agriculturalists as the "Esperance Sand Plain". The deposits concerned are considered equivalent in age to the red sand plain deposits which occur further inland.

The sand may be a few inches to several feet thick, and has been considerably resorted by wind action. Sand and pisolites overlie a yellow mottled clay, which in most places has developed on top of the Pallinup Siltstone. In saline areas the yellow clay is broken into domed structures, which are separated by wide desiccation cracks filled with the sand and pisolites. Pisolites are also incipiently developed near the top of the clay.

Deposits on the Lower Sand Plain. A second, and lower sand plain development, forms a step-like feature on the southern edge of the plateau, at an elevation ranging between 150 and 250 feet above sea level. It has a very thin grey sand cover, little development of pisolites, and exposes wide areas of yellow clay and eroded surfaces of the Pallinup Siltstone. The deposits are considered to be a younger development of the Esperance Sand Plain deposits.

Younger sediments; Pleistocene (?) and Recent

Eolianite, submerged beach rock, and marine sands. Carbonate rich eolianite occurs in places where it is piled up and fills gaps between coastal hills formed from bedrock. West of Esperance the eolianite is being eroded by the sea to form steep coastal scarps. Offshore from wide bays, fossil beach rocks have formed steps in the submarine profile at depths of 25 to 30 feet, 35 to 40 feet and 55 to 70 feet respectively. Drilling near the Esperance townsite, and dredging in the harbour, have encountered shelly bryozoan marine sands which occur to a depth of 80 feet below the present sea level. These deposits are considered to be late Pleistocene.

Dissected alluvium. Red clayey alluvium covers dissected flood plains and small river terraces, which stand about 20 feet above the present flood plain levels.

Red soil. Deep red clayey soil is located in erosion areas lying just below the level of the sand plain plateau. The soils appear to have been formed mainly from weathered bedrock after the cessation of a period of active headwater erosion and river rejuvenation, which was probably related to a late Pleistocene to sub-Recent low sea level.

Dune sands on the sand plain. On the red inland sand the dune sands are red, fine grained, and loamy.

Southwards, and towards the region of higher rainfall, the dunes become progressively leached, assume a white to grey colour, and are made of a more even-grained fine sand.

Beach rock. Beach rock composed of cemented, coarse-grained, slightly shelly quartz sand, forms long-shore bars as well as the outer edges of small lagoons in the centre of the longer sandy bars.

Coastal dune sand. White, fine to medium-grained quartz sand, forms rounded shaped dunes on coastal hills, and elongated dunes on the coastal plain and lower plateau. Bare foredunes of contemporary, marine-worked, fine-grained quartz sand occupy the shoreline. In some areas extensive blow-outs, and the remobilization of vegetated coastal dune sand has taken place.

In general these contemporary marine, beach, and fore-dune deposits, are very low in carbonates when compared with other similar Pleistocene deposits.

Alluvium. Grey to brown silt and clay deposits occur in the lower parts of river valleys, on flood plains, and in lakes and claypans.

Development of land forms

Apart from climatic factors, landforms have been developed by a number of base level changes. This is shown by the stepped form of the bedrock, the stepped plateau, stages of rejuvenation along rivers, river terraces, submerged shorelines, steps in the continental shelf, and a remarkable set of rock benches on the monadnock bedrock hills of the plateau and the coastal headlands and islands.

Rock platforms have been measured at levels of 750 to 800 feet, 530 to 570 feet, approximately 450 feet, 350 to 370 feet, 200 to 270 feet and at various other heights down to sea level. The bedrock bench at 200 to 270 feet is a conspicuous feature along the southern coastline (Clarke and Phillipps, 1952). Submarine rock benches on steep islands, headlands and reefs, have been observed in many places at depths of 20 to 28 feet, 36 to 42 feet, and 55 to 70 feet below sea level. Some of these benches predate the Upper Eocene because they can be seen to be emerging from a cover of Upper Eocene sediments (e.g. the bedrock platform underlying the western side of the Sheet area shown on Figure 2).

Rock benches on the granitic inliers are thought to have been originated mainly by variations in the depth of weathering caused by changes in sea level, and not necessarily as a direct result of wave action on the coast. Large round boulders which are found on hill tops probably indicate the base of an earlier weathering profile.

The sand plain was apparently developed in the mid-Tertiary, and presumably after the lower Miocene transgression. Massive leaching of carbonate resulted in the formation of many sink-holes, and caused a wide settling of the sediments in the deeper shelf part of the Neridup area. The fixing of iron to form pisolites in the Neridup area and the formation of some massive ferruginous layers in the western platform area, occurred towards the end stages of plain formation.

Dissection to produce an elevated sand-plain plateau occurred in stages during Pleistocene low sea levels. A late Pleistocene to Recent low sea level rejuvenated rivers which formed gorges near the coast, dissected alluvial flood plains, and caused widespread stripping to take place along the upper parts of old valleys. Rejuvenation ceased when the sea returned to its present level.

There is little direct evidence of Pleistocene sea levels rising more than 10 feet, but there is considerable evidence in the form of drowned shorelines and shelf steps, to confirm the existence of a number of low sea levels. Drowned shorelines of cemented beach rock have been measured at horizons of 20 to 28 feet, 36 to 42 feet, and approximately 60 feet below sea level. These correspond to submerged rock benches found off steep islands and headlands.

Step-like features are encountered in the bathymetry of the shelf at 90 to 120 feet, and a wide bench occurs between 180 to 330 feet (Carrigy and Fairbridge, 1954). Several drainage-like depressions run from the shoreline to this bench. The shape of these features indicates that they have been formed by the erosion of soft Upper Eocene sediments during stages of extremely low sea levels, rather than by marginal faulting.

At present, active erosion of the coastline is taking place, and sea cliffs and escarpments are being formed where wave action is eroding eolianites and Eocene sediments. In bays the formation of offshore unstable sand platforms with steep outer edges is in progress. In general, the continental shelf profile shows a marked steepening towards the shoreline, which helps to remove sediments away from the coast. The movement of offshore sand explains the absence of shelly remains and carbonated material on open beaches.

The longshore drift is just sufficient in places to maintain sedimentation in protected, east-facing bays (where sand trapping is assisted by a dense growth of ribbon weed), and to maintain a few unstable sand spits to land-tied islands. Severe erosion of the shore has been caused by the construction of landbacked berths at Esperance. There is little evidence to show the presence of contemporary wave-cut benches. Wave ramparts usually end abruptly seawards in near-vertical convex slopes of some 10 to 50 feet in height, which plunge down from near sea level to a sandy sea bed.

The location of rocky promontories is determined mainly by the presence of migmatites. The shape of headlands, islands, and reefs is controlled by prevailing rock trends and jointing.

STRUCTURE

An interpretation of the structure of the Esperance-Mondrain Island sheet is given in figure 1.

Folding

Folding consists mainly of a series of parallel overturned anticlines and synclines. The dominant fold trend is northeast-southwest in the southern part of the sheet. The trend swings to the north-northeast towards the north of the sheet area.

ECONOMIC GEOLOGY

Underground water

Six hundred water bores were located in the field census which was completed in 1967, and all of these are sited in the southern part of the Sheet area. Drilling activity however, has slowed considerably since the initial rapid farm development work took place in the period from 1956 to 1966. Generally it can be shown that bore sites located by geologists have been about twice as successful in finding water as those sited by others.

In this region there appears to be little interest in underground water which contains more than 5,000 parts per million of total dissolved solids. This attitude is probably influenced by the special requirements demanded by intensive stocking and breeding, and the availability of better, and fairly reliable alternative supplies from farm dams. Another reason is that a considerable part of the drilling activity is directed towards locating potable water on farms. Good quality groundwater is favoured as a domestic supply, because it has a lower turbidity than farm dam water.

The Quaternary coastal sand and the Plantagenet Group formations contain the main aquifers. The water has a wide range in salinity, and usually occurs at depths of less than 75 feet. Supply rates are usually small due to the fine-grained character and silty nature of the water-bearing horizons.

The Quaternary coastal sand, just west of the town of Esperance, contains a large storage which probably exceeds 11,800 million gallons (Morgan, 1969). This is hard water, with less than 1,000 parts per million of salts, and is being developed for a town water supply. The Quaternary sands are usually fine grained, and wells have to be specially constructed to yield more than 5,000 gallons per hour.

The Plantagenet Group generally have a low permeability due to cementing and the presence of silt. Running silts cause considerable problems in developing bores, and result in the failure of a large number of established bores. Good supplies of water can be located near the coast in the Plantagenet Group formations where it occurs in solution channels in silicified sponge limestone, and also from the basal conglomerate found in the elevated, western part of the Sheet area.

In the western part of the sheet area, bedrock is more elevated and the Plantagenet Group aquifer occurs in isolated pockets in valleys and on hill slopes (Berliat, 1952). In the eastern part, the Plantagenet Group is lower lying and thicker, and gives rise to a continuous aquifer system which is penetrated here and there by island-like monadnocks of granitic bedrock.

Figure 3 shows the location and salinity of bores on the Sheet area. It also shows a generalized relationship between rainfall, topography, and regional groundwater salinity.

Local rainwater intakes, such as the periphery of granite hills (Rowston, 1967), or permeable sink-hole zones, are important factors in localizing accumulations of fresher water within the regional salinity pattern shown in Figure 2.

The comparatively high groundwater salinity encountered on the south coast, when compared with other parts of the State, is considered to be due to a greater deposition of airborne salts carried in from the sea. The air in the southern region has a consistent high moisture content (Table 1), while sea breezes, dusty air conditions, and light misty rains are characteristic. All these factors favour the carriage of a large amount of salt. The heath-like vegetation of the Esperance region may have a salt-trapping effect (Eriksson, 1955), and a considerable deposition of salt could occur that would not be detected in rain gauges.

Soil, clay, and road gravel

Agricultural exploitation of the "Esperance Sand Plain" has been made easier by the existence of clay which lies on top of the Pallinup Siltstone at a shallow depth under the barren, leached, sand surface. When clay occurs at such depths it causes an early build-up of soil moisture, and restricts the downward leaching of added fertilizers.

It also provides an impermeable base for the construction of farm dams and roaded catchments.

Clays from the Pallinup Siltstone have been tested for brick making. The main deficiencies are the thinness of the beds and a high sand content.

A concentration of pisolites in many places provides a ready source of road building gravel.

Building stone, and rock aggregates

Unweathered granitic rocks, which are exposed close to the town and railway, offer a ready supply of rock for concrete, road metal, railway ballast, and breakwater construction. Some of the attractive granites near Esperance may also have possibilities as a material to face buildings.

Glass sand

Abundant, clean, fine quartz sands which are suitable for glass making occur in the area.

Salt deposits

Very small salt deposits have been worked in the past on Lake Warden.

Limestone

Sandy eolianite limestone has been used as a source of agricultural lime. Some of the eolianites warrant investigation as a building stone.

Heavy minerals

Only very small accumulations of heavy minerals, low in ilmenite, have been located along existing beaches.

Phosphates

Islands of the Archipelago of the Recherche were examined for guano deposits (Dulfer, 1943), and some very small cave deposits were found on islands included in the Mondrain Island Sheet area. A number of samples obtained from rocks of the Plantagenet Group and coastal limestones was tested, but the results were disappointing. Nothing is known of the possible occurrence of submarine phosphates.

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TABLE 1

CLIMATIC DATA - ESPERANCE

No. Years		Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
30	Average daily maximum temperature (°F)	76.6	77.5	75.4	72.2	67.4	63.5	62.1	63.5	66.4	68.4	71.9	74.5	70.0
30	Average daily minimum temperature (°F)	59.9	60.3	58.9	54.4	50.3	46.8	45.4	45.7	47.9	50.3	54.4	57.5	52.6
30	Monthly mean temperature (°F)	68.2	68.9	67.2	63.3	58.8	55.1	53.7	54.6	57.1	59.4	63.2	66.0	61.3
30	Average index of mean relative humidity (%)	70	69	72	75	77	77	77	77	72	73	71	70	73
44	Average daily 3 pm relative humidity (%)	63	64	64	65	64	65	65	62	63	64	64	63	64
30	Average monthly and yearly rainfall (pts)	79	70	125	192	361	393	420	376	260	204	100	87	2673

TABLE 2

STRATIGRAPHY OF THE ESPERANCE-MONDRAIN ISLAND SHEET

Age	Group	Formation or Map Unit	Map Symbol	Lithology	Remarks
CAINOZOIC – RECENT		Alluvium	Qra	silt and clay deposits	along rivers, flood plains and lakes
		Fore dunes	Qrf	coastal sand	bare mobile coastal dunes, coastal fore dunes, blow-outs
		Coastal dunes	Qrd	coastal sand	forms long parallel dunes on the coast plain
		Coastal hill dunes	Qrc	coastal sand	coastal sand heaped on coastal hills
		Beach rock	Qrb	coarse-grained, shelly, cemented sand	
CAINOZOIC – PLEISTOCENE?		Alluvium	Qpa		high level flood plains and river terraces, partly dissected
		Sand dunes	Qps	white, leached, fine-grain quartz sand	forms long WNW trending dunes and rounded dunes
		Sand dunes	Qpf	red; loamy; fine grained	dunes inland from Qps dunes
		Eoleonite	Qpl	carbonate cemented eoleonite	forms coastal hills
		Red soil	Qpr	red soil from weathered gneiss and granite	in erosion areas near the head waters of the younger river channels
		Sand plain deposits	Qpp_2	grey sand with rare pisolites over yellow clay	occupies a lower dissected plateau between 150 to 250 feet above sea level
		Sand plain deposits	Qpp_1	grey sand over pisolites, over yellow clay	occupies a dissected sand plain (Esperance Sand Plain), generally more than 250 feet above sea level
		Red sand plain	Qpi	red loamy sand over white limestone over greyish to greenish clay	continuous inland from Qpp, sand plain deposits

TABLE 2 - continued

CAINOZOIC / TERTIARY	Plantagenet Group	Weathered rock	Tep	deeply weathered rocks	
		Pallinup Formation	Tew	yellow to grey claystone, siltstone silty sandstone with sponge and mollusca fossils	
		Werrilup Formation	To	grey foraminiferal clayey sandstone and dark grey carbonaceous siltstone and sandstone	concealed
PROTEROZOIC		Pegmatite	P		
		Aplite	a		
		Quartz	q		
		Granite	P€g	coarse, even-grained to porphyritic, pink, feldspar lath granite	
		Basic dyke	b	biotite	
		Migmatite	P€m	alternating bands and mixed rocks composed of lath granite and garnet gneiss in varying proportions	
		Gneiss	P€n	banded garnet, biotite gneiss and granitic rocks of varying composition	
		Basic dykes	n	amphibole	
		Undifferentiated Proterozoic rocks	P€		
ARCHAEAN		Possible Archaean	A	?Granite	Not yet seen in outcrop

TABLE 3

G.S.W.A. NERIDUP BORE No.21
(Reg.No.SI/51-6-3330-I/C-17)

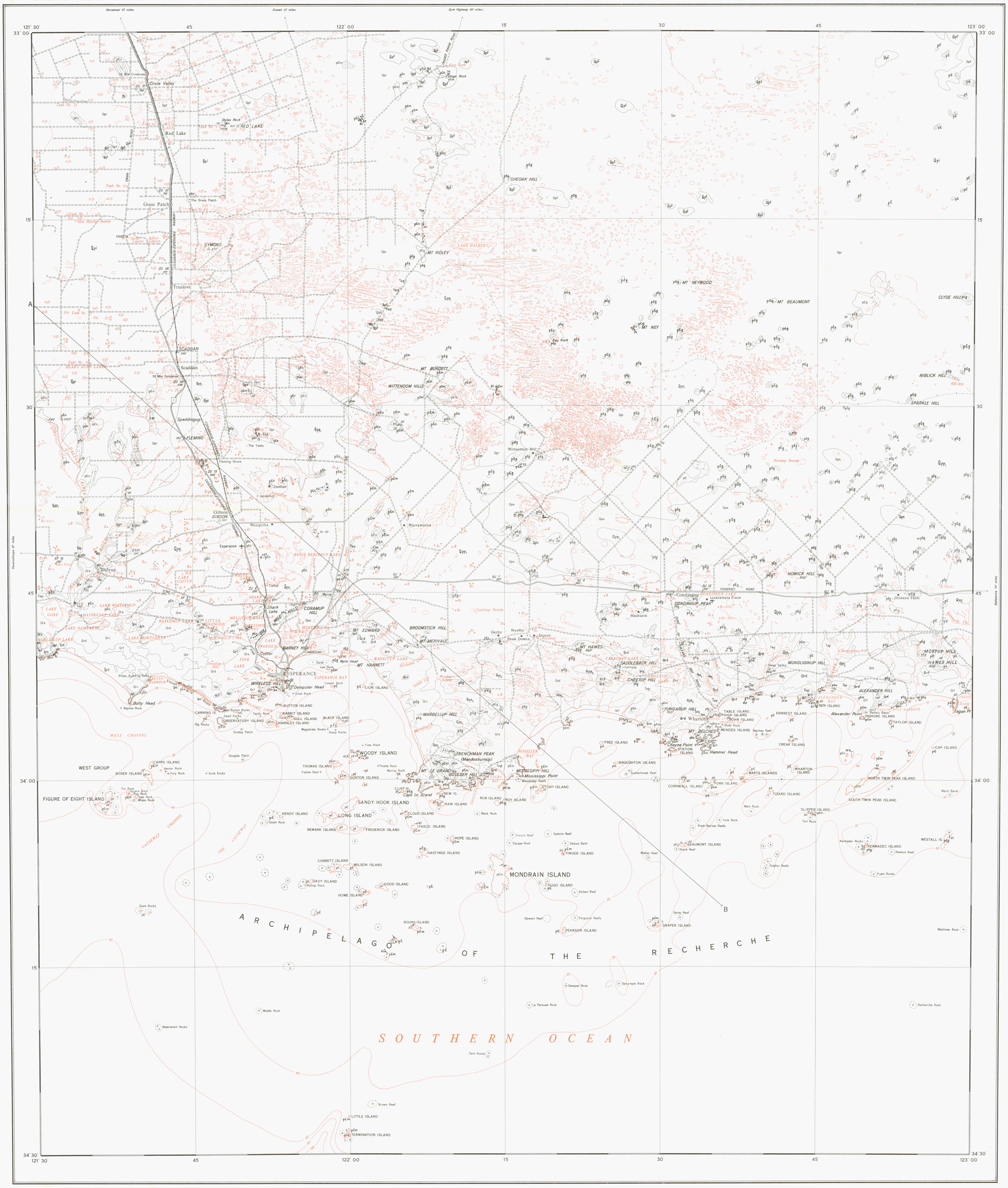
Depth below surface in feet	Thickness in feet	Lithology	Formation
0- 1	1	Grey sand	
1- 8	39	Deep yellow, friable siltstone	Pallinup Siltstone
8- 10		White hard siltstone	
10- 30		Yellow to light yellow, porous, fine-grained silty sandstone	
30- 40		Yellow silty sandstone with highly rounded and frosted quartz grains	
40- 55	110	Buff, grading to brown, medium grained, sandstone	Werillup Formation
55- 59		Dark brown, porous, medium grained sandstone, with highly rounded translucent, slightly brown stained, quartz grains	
59- 75		Black (carbonaceous), silty, fine grained sandstone	
75- 90	75	Grey, porous, highly fossiliferous, silty, fine to medium grained quartz sandstone, with well rounded transparent grains	Nanarup Limestone Member Equivalent
90-105		Grey, silty, highly fossiliferous sandstone, with foraminifera and echinoid spines	
105-125		Grey, silty, highly fossiliferous, quartz sandstone	
125-150		Grey, clayey to silty, fossiliferous, sandstone	
150-151	1	Weathered granite	
151-152	1	Grey silicified granite	

ESPERANCE - MONDRAIN ISLAND

AUSTRALIA 1 : 250,000 GEOLOGICAL SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SI 51-6 AND PORTION OF SHEET SI 51-10



REFERENCE

CAINOZOIC

QUATERNARY — RECENT

Qra	Alluvium—silt and clay deposits along rivers, flood plains and lakes
Qrf	Foredune sand—bare, mobile coastal sand, coastal foredunes, blowouts
Qrd	Coastal dune sand—coastal sand forming long parallel dunes on the coastal plain
Qrc	Coastal hill dunes—coastal sand heaped on coastal hills
Qrb	Beach rock—coarse grained, shelly cemented sand

QUATERNARY — PLEISTOCENE ?

Qpa	Dissected alluvium—high-level flood plains and river terraces, partly dissected
Qps	Dune sand—white, leached, fine-grained quartz sand forming long WNW trending dunes and rounded dunes
Qpf	Dune sand—red, loamy, fine-grained sand dunes inland from the Qps dunes
Qpl	Eolianite—submerged beach rock and marine sand; carbonate-cemented eolianite forming coastal hills. Shelly beach rock forming submerged bars at various depths, concealed shelly marine sand
Qpr	Red soil—red soil from weathered gneiss and granite in the erosion areas near the headwaters of the younger river channels
Qpp_2	Lower sandplain deposits—grey sand with rare pisolites over yellow clay, occupying a dissected plateau between 150'-250' above sea level
Qpp_1	Sandplain deposits—grey sand over pisolites over yellow clay, occupying a dissected sandplain ("Esperance sandplain") generally more than 250' above sea level
Qpi	Red inland sandplain—deposits red loamy sand over white limestone over grey to greenish clay, continuous inland from the Qpp sandplain deposits. Grey billy and cemented pisolites on elevated ground

TERTIARY ? — Plantagenet Group

Tep	**PALLINUP SILTSTONE**: yellow to grey claystone, siltstone, silty sandstone, with fossil sponges and molluscs
Tew	**WERILLUP FORMATION** (concealed): grey foraminiferal clayey sandstone and dark grey clayey carbonaceous siltstone and sandstone
To	Weathered bedrock—yellow to red deeply weathered bedrock

PRECAMBRIAN

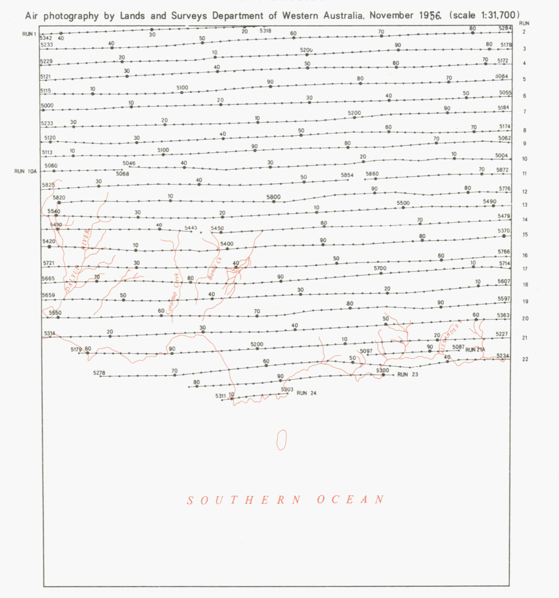
p / q	Acid dykes—pegmatite p ; quartz q
p€g	Granite—coarse, even-grained to porphyritic, pink lath feldspar granite
b	Basic dyke—biotitic rock
p€m	Migmatite—alternating bands and mixed rock composed of lath granite and garnet gneiss in varying proportions
h	Basic dyke—amphibolite rock
p€n	Gneiss—banded, garnet-biotite gneiss and granitic rocks of varying composition and texture
p€	Undetermined Precambrian rocks mapped by photo interpretation

SYMBOLS

Geological boundaries	
Accurate	
Approximate	
Inferred	--?------?--
Strike and dip of bedding	
Foliation	
Strike and dip	60
Foliation with plunge of lineation	60 40
Banding, platy flow	
Inclined, l : lath feldspar	40
Lineation	
Quartz	q 40
Amphibolites	h 40
Quartz rods, mullions, minor folds, shown by banding	r 40
Unspecified	
Trend line	
Folding	
Dragfold	
Dragfold showing plunge	
Joints	
Strike and dip measured	40
Vertical	
Pattern	
Specimen locality	× 17023
Fossil locality	
Railway, 3' 6" with station or siding	Speddingup
Highway with national route marker	1
Formed road	
Track	
Airfield	
Landing ground	
Homestead	■ Garby
Building	
Locality	• Castletown
Horizontal control, major	293' WIRELESS HILL
Bench mark, height accurate	ZU13 508'
Quarry	
Watercourse	
Permanent	
Intermittent	
Lake perennial, intermittent	
Swamp	
Claypans	
Soak	• Sk
Well	• W
Bore	• B
Spring	• S
Rockhole	• RH
Gnamma hole	• GH
Tank, earth	T
Dam	D
Wharf	
Lighthouse	
Wreck, exposed	
Fathom line, approximate	20
Coral bank or submerged rock	
Reef, exposed	
Position doubtful	(PD)
Abandoned	(Abd)
Sand dune, ridge, lunette	

FLIGHT DIAGRAM

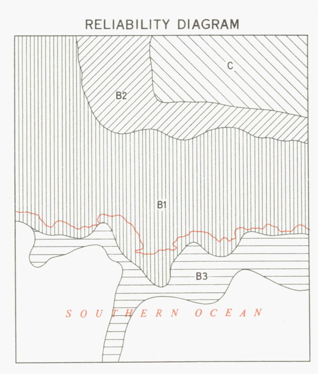
Air photography by Lands and Surveys Department of Western Australia, November 1956. (scale 1:31,700)



Compiled by Geological Survey of Western Australia. Cartography by Geological Drafting Section, Mines Department. Topographic base from compilations by Lands and Surveys Department. Printed by Government Printing Office, Perth.

Copies of this map may be obtained from the Geological Survey of Western Australia, in Perth.

RELIABILITY DIAGRAM



B1 Numerous traverses with air photo interpretation

B2 Air photo interpretation with a few traverses

B3 Few traverses including few submarine observations (no air photos available)

C Air photo interpretation

HON. D.G. MAY, M.L.A.
MINISTER FOR MINES
J. H. LORD, DIRECTOR, GEOLOGICAL SURVEY

SCALE 1 : 250,000

5 0 5 10 15 20 Miles

10,000 0 10,000 20,000 30,000 Yards

5 0 5 10 15 20 25 30 Kilometres

TRANSVERSE MERCATOR PROJECTION

ZONE 2 AUSTRALIA SERIES

DIAGRAMMATIC SECTION A - B

VERTICAL SCALE: UPPER SECTION $\frac{V}{H}$ = 15

LOWER SECTION—NATURAL SCALE

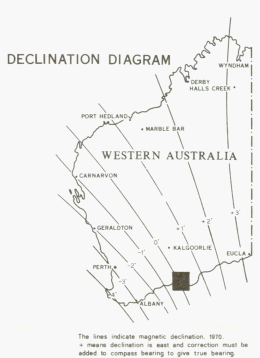
Geology by K. H. Morgan, 1967

INDEX TO ADJOINING SHEETS

LAKE JOHNSTON SI 51 - 1	NORSEMAN SI 51 - 2	BALLADONIA SI 51 - 3
RAVENSTHORPE SI 51 - 5	ESPERANCE SI 51 - 6	MALCOLM SI 51 - 7
	MONDRAIN IS. SI 51 - 10	CAPE ARID SI 51 - 11

S O U T H E R N   O C E A N

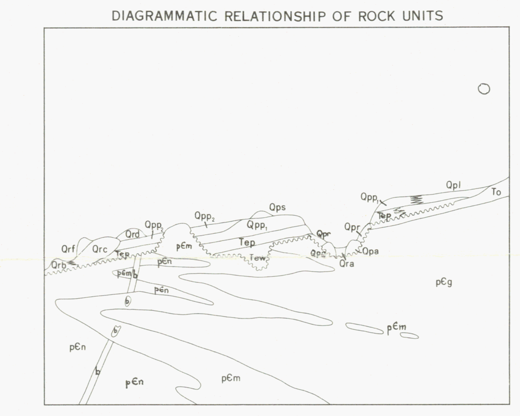
DECLINATION DIAGRAM



The lines indicate magnetic declination, 1970.
+ means declination is east and correction must be added to compass bearing to give true bearing.
− means declination is west and correction must be subtracted from compass bearing to give true bearing.

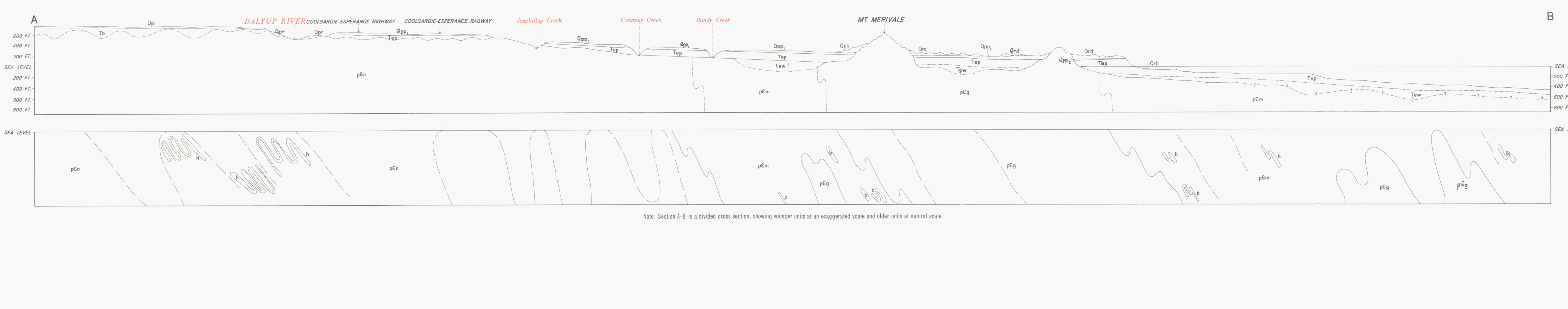
Annual change is negligible

DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS



Unconformity

Change of facies



Note: Section A-B is a divided cross section, showing younger units at an exaggerated scale and older units at natural scale

ESPERANCE - MONDRAIN ISLAND

SHEET SI 51-6 AND PORTION OF SHEET SI 51-10

FIRST EDITION 1972

PRELIMINARY PRINTING, 1972

SUBJECT TO AMENDMENT

12794

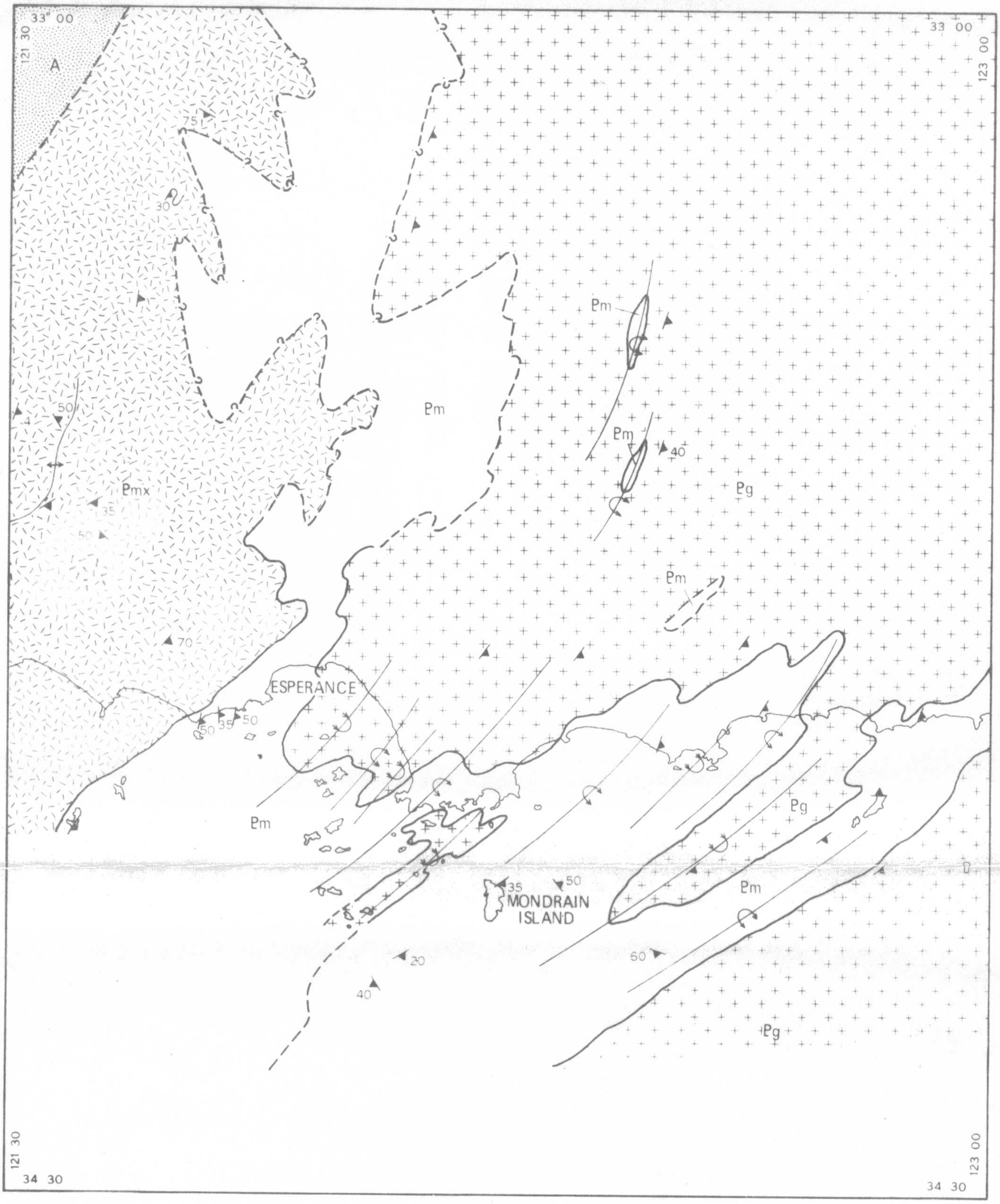
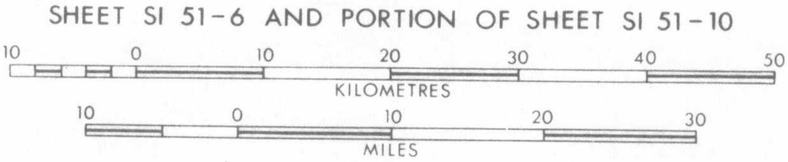


FIGURE 1

STRUCTURAL SKETCH MAP

ESPERANCE - MONDRAIN ISLAND

SHEET SI 51-6 AND PORTION OF SHEET SI 51-10

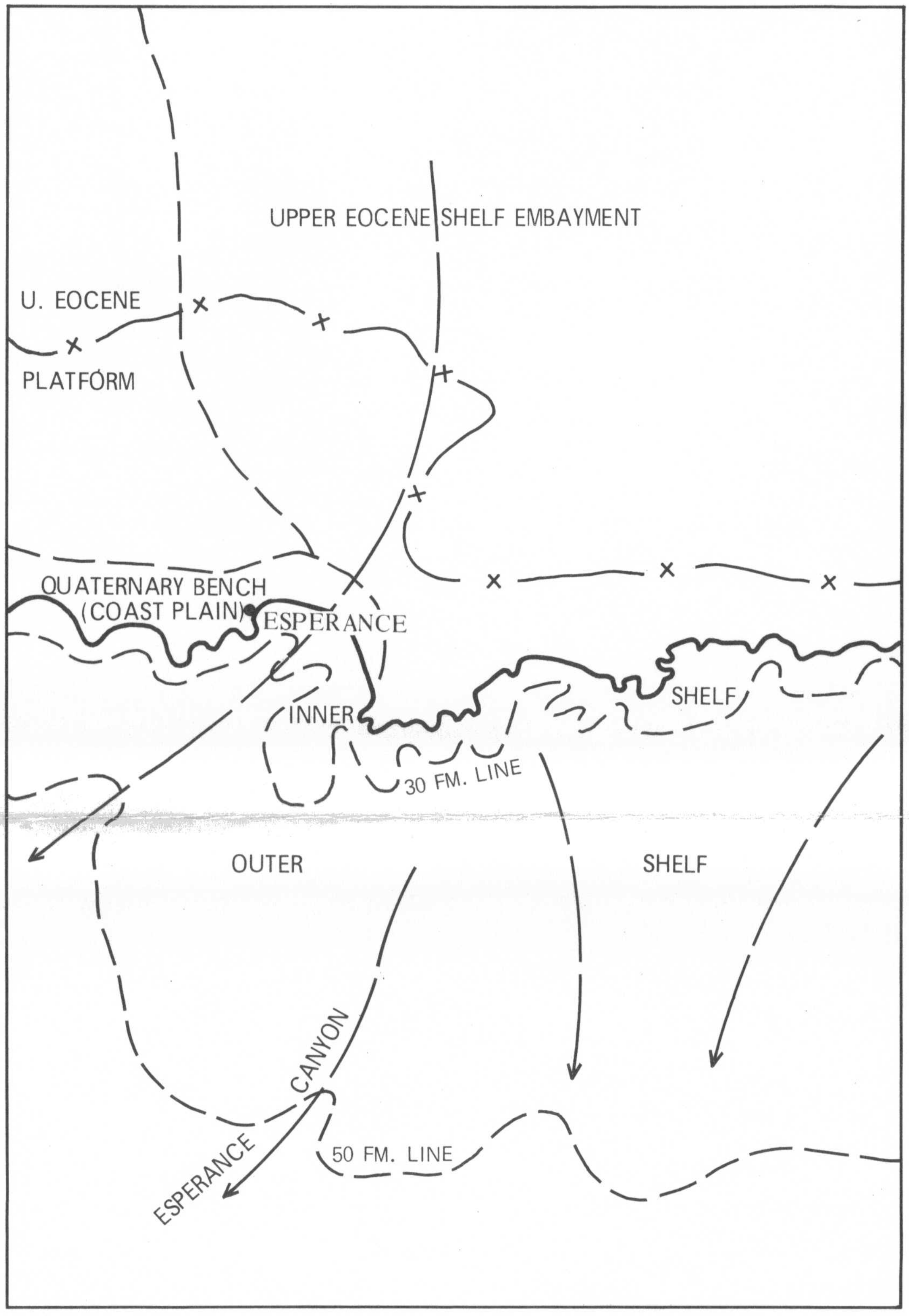


REFERENCE

Ꝑg	Granite not subdivided
Ꝑm	Migmatite of granite and gneiss Gneiss is probably Ꝑmx
Ꝑmx	Gneissic migmatite
A	Possible Archaean
50 (symbol)	Foliation dip and strike
(symbol)	Anticline
(symbol)	Overturned anticline
(symbol)	Overturned syncline
———	Geological boundary
– – – –	Geological boundary approximate
– –?– –	Geological boundary inferred

12413

FIGURE 2



REFERENCE

—— x —— Step at halted rejuvenation

— — — Marine shelf boundary

——> Possible pre–U. EOCENE drainage lines

CONTINENTAL SHELF STRUCTURES

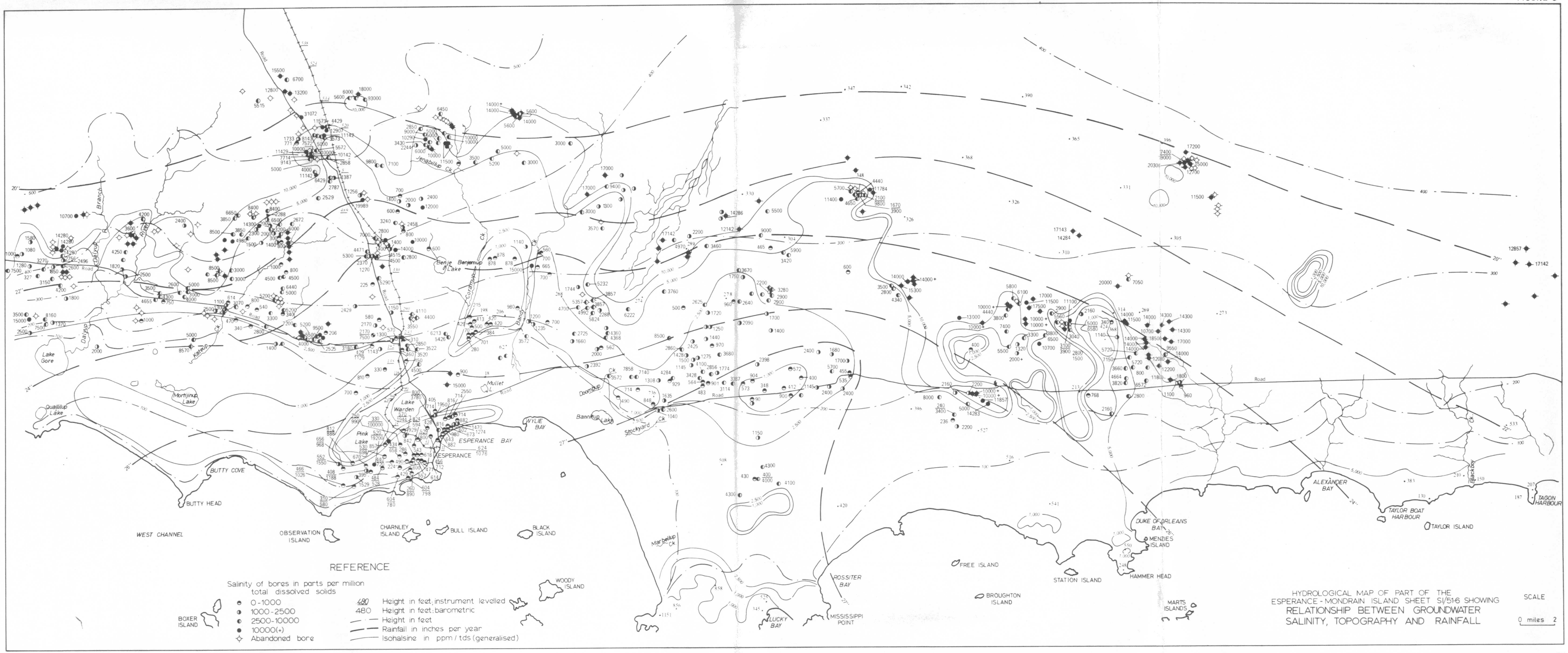
UPPER EOCENE TRANSGRESSION TO RECENT

SCALE 0 – 16 miles

1:1,000,000

10943

FIGURE 3



9860