COMMONWEALTH OF AUSTRALIA.

DEPARTMENT OF NATIONAL DEVELOPMENT.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS.

BULLETIN No. 28.

BEACH-SAND HEAVY-MINERAL DEPOSITS OF EASTERN AUSTRALIA

BY

D. E. GARDNER.

Issued under the Authority of Senator the Hon. W. H. Spooner, Minister for National Development.

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COMMONWEALTH OF AUSTRALIA.

DEPARTMENT OF NATIONAL DEVELOPMENT.

Minister : SENATOR THE HON. W. H. SPOONER.

Secretary : H. G. RAGGATT.

BUREAU ON MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS.

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SUMMARY.

Beach-sand deposits containing zircon, rutile, ilmenite, and monazite occur on the Australian east coast, mainly between Stradbroke Island, Queensland, and Tallow Beach south of Byron Bay, New South Wales. Smaller deposits are known as far north as Frazer Island and at several localities southwards to Catherine Hill Bay, near Lake Macquarie. The Stradbroke Island deposits have been tested by Zinc Corporation, and the beach deposits from Stradbroke Island to Frazer Island by the Queensland Geological Survey. Those between Southport and the Clarence River were bored, sampled, and mapped by the Bureau of Mineral Resources, Geology and Geophysics between 1947 and 1951. A field laboratory at Southport was equipped for rapid separation of samples into their constituent minerals. Electronic equipment was installed for estimating the proportions of monazite in the samples, and of thoria in the monazite. In this report the source rocks of the sand and heavy minerals are considered in a brief outline of the physiography and general geology of the country between the coast and the main divide. The deposits are described and their origin and distribution discussed in connexion with late Pleistocene and recent changes in sea level. The reserves and distribution of the heavy minerals are broadly summarized, and more details of reserves and of dimensions of deposits and overburden are given in descriptions of the individual areas.

INTRODUCTION.

Beach sand deposits along the Australian east coast (Gardner, 1951 *a, b*) have yielded a large part of the world's supply of zircon and rutile since the year 1936. During 1953 the returns from the export of these minerals amounted to more than £2,000,000. In addition the black sands contain a small proportion of monazite, which is a source of cerium and of thorium, a fissionable element that may be used for the generation of atomic power. From a comparatively small beginning in the mid-1930's the beach-sand industry grew rapidly during the war and early post-war years. Little was known of the distribution and reserves of the deposits; hence the Bureau of Mineral Resources undertook a detailed investigation of the coastal area between Southport, Queensland, and Woody Head a little north of the mouth of the Clarence River, New South Wales. The primary object of the survey was to determine the reserves of monazite and therefore of thorium; the reserves of zircon, rutile, and ilmenite were also determined.

During 1947 the Queensland Geological Survey carried out a reconnaissance investigation of the beaches from Stradbroke Island to Frazer Island (Connah, 1948; Morton, 1948). Other testing, by private concerns, comprised boring and sampling by Zinc Corporation on North Stradbroke Island, Queensland, and at Norries Head, New South Wales (Donaldson and Stuart, 1948); by Alluvial Prospectors Ltd., at North Labrador, 3 miles north of Southport; by Alluvial Gold Ltd., near Norries Head; and by Zircon Rutile Ltd., at Tallow Beach.

The investigation by the Bureau of Mineral Resources started in July, 1947, when a field laboratory was established in a wartime building at Southport. Early work included a contour survey of an area at Tallow Beach tested by Zircon Rutile Ltd., the examination of samples obtained by the Queensland Geological Survey in its reconnaissance investigation, the estimation of reserves of monazite in tailings and other concentrates along the coast, and routine testing at separation plants with the object of devising an inexpensive method of obtaining monazite as a by-product.

Systematic field work started in January, 1948, and finished in December, 1950. During 1948. much time was given to purchasing, carting, and stock-piling monazite concentrates for the Commonwealth Government.

The author was in charge of the investigation, and J. Ward was responsible for the laboratory work throughout. Other Bureau geologists who participated for shorter periods included J. O. Cuthbert, T. D. Dimmick, J. E. Glover, N. H. Krasenstein, and D. M. Traves; and geophysicists included J. Newman, L. W. Williams, and Miss L. M. Edhouse.

The area is traversed by the Pacific Highway, which is generally much less than 10 miles from the coast. Access to the beaches and dunes is simple between Southport and Coolangatta: this stretch of coast, being a popular holiday resort, is closely subdivided for building, and provided with good roads. Between Fingal Point and Cudgen Point, bitumen roads run relatively close to the beaches, but motor transport along Letitia Spit and portions of the area south of Fingal Point is not practicable without four-wheel-drive vehicles. South of Cudgen Point, most of the headlands can be reached by road, but the beaches and dunes are provided, at the best, with sand tracks suitable only for four-wheel-drive vehicles. The stretch between Evans Head and Woody Head is particularly difficult, because much of it tends to be swampy, and the weather was unusually wet at the time that it was being investigated.

Rail transport is provided by the State Government Railways of Queensland, which run as far south as Tweed Heads on the State border, and of New South Wales, which terminate at Murwillumbah, 14 miles to the south-west of Tweed Heads. The closest ports suitable for oversea shipping are at Brisbane, Queensland, and Newcastle, New South Wales.

METHOD OF INVESTIGATION.

Field Work.

General.

Jeeps and trailers were used for transport in the field, one being allocated to each boring party of four men. The field party camped in or close to the area that was being tested,, using equipment supplied by the Bureau. Unskilled field assistants were recruited for the investigation, and taught the work required.

Boring and Sampling.

The beaches and adjacent dunes were sampled by boring along lines sited at right angles to the beaches. South of Cudgen Point the bore-lines were 1,000 feet apart. Along each line, the bores were at intervals of 30 feet across the beaches and 40 feet across the dunes. North of Cudgen Point, much of the coastal area was occupied by townships and settlements, and standard distances between bores and bore-lines were not practicable.

Before a line was bored, it was marked out and cleared of scrub, and pegs were driven in at the prospective bore-sites. The levels of the bore-collars were then determined with respect to high-water-mark on the beach, using either a plane table and alidade, or a theodolite. This made it possible to bore accurately to the desired depth.

When work started in a new area it was usual to restrict boring initially to each fourth or eighth line. These were regarded as scout-boring lines, and were extended some distance landwards from the beach, in order to locate, approximately, the boundaries of any deposits in the area. In later bore-lines, placed between the scout lines, it was possible to predict roughly the positions of the deposit, and avoid much unnecessary work. Boring usually began at the top of the beach, or on the foredune, where a seam of heavy mineral was almost invariably found. Bores were then continued across the beach at 30-ft. intervals, and across the dunes at 40-ft. intervals. When a bore-hole failed to yield heavy minerals, the interval was increased to 80 feet. In scout-bore lines the interval was increased commonly to 120 feet, and in places to 400 feet.

Boring to ground-water level was by means of a post-hole digger or auger, 4 inches in diameter. The sand a few inches below the surface was generally sufficiently damp to be retained in the auger and to stand in the bore-hole, except during long spells of hot dry weather, when at times it had to be dampened by pouring water down the bore-hole. For each 3 feet of depth the sand taken from the bore-hole was quartered down to a sample of about 1000 cc. When heavy minerals were visible in the sand brought up by the post-hole digger, indicating the presence of a seam, it was sampled separately. The samples were stored in cloth bags and transported to the field laboratory at Southport.

Mapping.

The plans of the areas investigated include Plates 2 to 10, which are drawn on scales of either 1 mile or 2 miles to the inch, and Plates 11 to 26, on a scale of 1,000 feet to the inch. The small-scale plans show the general geology, localities of mineral deposits, and some of the cultural features of each area. They are based on Lands Department maps and military maps, and the boundaries on them were obtained by field mapping and interpretation of aerial photographs. The larger-scale plans show bore-sites, mineral deposits, and leases, and included with them are sections along some of the bore-lines. Those covering the area between Southport and Coolangatta are based on large-scale Lands Department plans. The bore-sites and boundaries were plotted by measuring to mapped features such as fence lines. Between Tweed Heads and Cudgen Point the settlements are more scattered, and plotting on to Lands Department maps was supplemented by mapping with plane table and alidade. South of Cudgen Point the bore-sites and leases were mapped by means of theodolite surveys.

LABORATORY WORK.

General.

The laboratory work amounted essentially to a qualitative and quantitative estimate of the heavy minerals in the bore samples, after separating them from the white quartz sand which invariably accompanied them. The samples received from the field were dried in the sun, or on a fuel stove during wet weather. A standard volume, either 700 cc. or 500 cc., was measured out and weighed, the heavy minerals separated from it, and the heavy concentrate dried, weighed, and its volume determined. This work and the recording associated with it was done by field assistants, who spent about one week in every three at the laboratory. The subsequent work—determining the composition of the heavy concentrate—was done by a geologist in charge of the laboratory work.

Separating Heavy Minerals from Sample.

Except during the early stages of the work, when a panning dish was used, the heavy minerals were separated from the quartz sand by gravity concentration on a laboratory-model Wilfley table constructed by Otis

Engineering Co. of Melbourne. Because of the small volume of sand in each sample, the deep wooden riffles supplied with the table were replaced by copper strips, cemented in place with "Bostik" adhesive compound. Separation was improved by inclining them at a slight angle to the table, so that the mineral grains were forced to climb a little while moving along the table. The samples differed greatly in their relative proportions of heavy mineral, and to attain satisfactory separation it was necessary to change for each sample the rate of flow of water across the table, and the setting of the knife-edges dividing concentrate, middling, and tailing. Complete separation was generally obtained by a single re-tabling of the middling, but in very high-grade and relatively low-grade samples, the middling had to be re-tabled twice. Four men were commonly employed for tabling: two to attend to drying, weighing, and determining the volume of samples and concentrates, one to feed sample to table, and one to take off the concentrate. About 100 to 150 samples per day were treated.

Determining Composition of Concentrate.

The heavy minerals in the beach sands are zircon, rutile, ilmenite, a little monazite, and varying small amounts of other minerals, mainly garnet and tournaline. Their relative amounts may be obtained by grain-counting, or by separating them electro-magnetically and electrostatically into their constituent minerals. The monazite and its thoria-content can readily be determined radiometrically. At an early stage of the laboratory work, the compositions were estimated by grain-counting, under a microscope. However, some of the rutile grains cannot be distinguished with certainty from ilmenite, and ilmenite had therefore to be removed electro-magnetically from the concentrate. By increasing the field strength of the magnet, the monazite, together with some garnet, was taken out from the remainder of the concentrate, and determined more accurately. This method of separating ilmenite, monazite-garnet, and zircon-rutile, and grain-counting the mixed concentrates, was relatively accurate, and for certain purposes it was refined by sieving the concentrate into two or more size grades, which were treated separately. However, it was too slow to cope with the numbers of samples arriving from the field. Equipment installed soon after the start of the investigation comprised an "Isodynamic" electromagnetic separator, supplied by H. G. Frantz of New York, an electrostatic separator manufactured by Mineral Deposits Syndicate, of Southport, and Geiger-Muller gamma-ray counting equipment fitted with an electronic counter. The ilmenite and monazite-garnet were separated out as before, and the zircon and rutile were separated electrostatically. By weighing the separated products, accurate figures were obtained for percentages of the principal minerals, and a less reliable figure for monazite. A better figure was obtained radiometrically. The thoria-content of the monazite in each area tested was estimated by comparing its count-rate with that given by a standard monazite-sample of known thoria-content. Then, knowing the thoria-content of the monazite—which proved to be nearly constant over a wide area—the monazite content of the sand was obtained by comparing its count-rate with that of the same volume of a standard sample. Allowance was made for the slight rise in count-rate due to a little radioactivity in the zircon.

PHYSIOGRAPHY.

Areas Drained by Principal Streams.

New England Plateau.

The main divide runs more or less parallel to the coast between Swansea and Fraser Island and about 70 to 100 miles from it, except around the headwaters of the Hunter-Goulburn river system in New South Wales, where it diverges to 130 miles, and the Burnett and Dawson-Mackenzie Rivers in Queensland, where it diverges to more than 200 miles. Both these divergences are partly tectonic in origin, being due to relative sagging of the areas during the repeated Tertiary uplifting of the Eastern Highlands. Between these two river systems the divide generally maintains an elevation of 3,000 feet, rising at intervals above 4,000 feet. In the New England upland area a cross-section would show a gentle curve from the west with a steeper descent to the coast. The New England Plateau owes its elevation partly to the resistant nature of its rocks, which are mainly granite and metamorphics, and partly to upwarping during the Mesozoic and Tertiary. In the north it slopes down eastwards to the Clarence Basin; in the south it rises above the lower coastward country at precipitous scarps in which deep gorges have been dissected by rejuvenated streams. Spurs of plateau country more than 3,000 feet high run eastward from the New England area both north and south of the Clarence Basin and approach close to the coast near Tweed Heads and Coffs Harbour.

Marginal Depressions.

Marginal depressions east of the Highlands include the Clarence Basin, the Hunter-Goulburn Trough, and the Cumberland Basin, in New South Wales; and the Moreton Basin in Queensland.

The Clarence Basin is composed mainly of soft Jurassic strata, overlain in the north and north-east by Tertiary basalt. Its coastal and central portions are relatively low-lying; and for the central portion at least this is a result of warping rather than erosion in late Tertiary times, since remnants of the Miocene peneplain can be recognized on it. To the west and north, where it rises to the New England Plateau and the Macpherson Range, it has been deeply dissected by the Clarence and Richmond Rivers and their tributaries.

The Moreton Basin north of the Macpherson Range is composed largely of Jurassic strata, and considerable areas are covered by remnants of Tertiary basalts. Its surface is at a low elevation where traversed by the lower part of the Brisbane River, but rises rapidly towards the highlands on the west and south. There, its slopes are dissected by the Brisbane, Albert, and Logan Rivers and their tributaries.

The Hunter-Goulburn trough is a tectonic depression in which lie the wide and deep valleys of the Goulburn and lower Hunter Rivers. The Goulburn River flows over Permian coal measures, uncovered by erosion of resistant Triassic Hawkesbury Sandstone, and its upper tributaries drain Tertiary basalts south of the Liverpool Range. The upper Hunter River and the southward-flowing tributaries of the lower Hunter flow over Carboniferous strata; the lower Hunter flows over Carboniferous and Permian sediments.

Extending southwards from the Hunter-Goulburn valley to Kiama on the South Coast is a triangular area in which hard Triassic sandstones overlie softer Permian strata. The rivers which drain it, the Hawkesbury, Wollondilly, and Cox's, flow through gorges in their lower parts, although the upper reaches have cut through the Triassic and widened their valleys considerably. A marginal depression, the Cumberland Basin, occurs within this area, west of Sydney. It is joined to the coast by a 20-mile wide corridor that encompasses Port Jackson and Port Hacking. The depression is tectonic in origin, and relatively little has been removed from the area by stream-erosion.

North Coast.

Flowing to the North Coast, between the Hunter and the Clarence, are the Macleay and Manning Rivers, whose headwaters flow from the main divide, and the Bellingen and Nambucca, which rise 30 miles or less from the coast. Between the Bellingen and Clarence Rivers a divide occurs within 10 miles of the coast, and the drainage west of it passes to northerly-flowing tributaries of the Clarence. The streams flowing eastward are intermittent creeks.

Stream Erosion.

The principal streams have their origin during the Tertiary period. Since then they have, generally speaking, followed the same valleys, although they have been diverted by Tertiary basalt flows, which obliterated old channels and buried their alluvial deposits. In the present-day valleys, alluvial terraces are found up to a few hundred feet above the streams. In the mature lower courses, terraces up to 20 feet above river level are common. Probably most of them are flood-plain deposits, and some near the coast can be attributed to eustatic changes in sea level.

The quantities of sediment and heavy minerals transported by the streams must depend on, among other factors, the amount of erosion being accomplished by them. The Clarence system and the Richmond River and tributaries have deeply eroded the slopes up to the highlands in the Clarence Basin; the Brisbane, Logan, and Albert Rivers have brought about similar erosion in the Moreton Basin. The principal North Coast rivers, the Macleay and Manning, have cut back deeply into the eastern slopes between the Clarence Basin and the Hunter-Goulburn trough, but they have removed a much smaller volume of material from their resistant terrain than has come from either of the two Jurassic basins. The erosion by the Hunter-Goulburn system is probably similar in amount to that caused by the North Coast rivers. The Hawkesbury/Wollondilly/Cox's River system seems to have accomplished relatively little erosion in the area of hard Triassic sandstone.

Coastal Physiography.

The Coastline.

Workable deposits of heavy minerals have been found along the east coast between Swansea, a little south of the Hunter River, and the northern end of Frazer Island, a distance of about 600 miles. Small accumulations of heavy minerals have been reported farther to the south and to the north, but no large deposits are known. The largest and richest deposits occur in the 100-mile stretch between Tallow Beach, south of Byron Bay, and the northern end of Stradbroke Island.

Between Swansea and Frazer Island, three types of coastline may be distinguished. From 2 miles to 15 miles north of Coffs Harbour and from the Nambucca River to the Bellingen River consolidated rock extends practically to the sea. Much of the shoreline is rocky, but short beaches occur between headlands. In strong contrast is the coastline from the Manning River to the Nambucca River, and from the Clarence River to Southport. The consolidated rock of the mainland is fringed by sandy, rather low-lying, coastal plains, which are extensive near the mouths of the principal streams. Their seaward edge is marked by sand dunes and long sweeping beaches. In places, consolidated rock extends as spurs to the coast, where it forms headlands, and breaks the continuity of the coastal plain. From Tuncurry to Port Stephens and from the Hunter River to Tuggerah Lake, south of Swansea, there is a similar disposition of beaches, dune-belts, and swamp, but the coastal plain is replaced wholly or in part by extensive lagoons or coastal lakes.

From Southport to Frazer Island the Coastal stretch is distinguished by the occurrence of sandy islands, one of which, Stradbroke Island, contains extensive deposits of heavy minerals. From the Clarence River to Frazer Island, the main masses of sand appear to be somewhat northwards from the mouths of the main streams, the Clarence, Richmond, Brisbane, and possibly the Mary, Rivers. This is a consequence of the strong northward movement of sand, evident in the northward extension of sandspits at the river-mouths.

Beach and Foredune.

A typical beach is made up of rather fine white quartz sand, and is one or two hundred feet wide, depending on the weather and the tide. It is arcuate in shape and may curve around between two headlands, or start at a headland, sweep northward along the edge of a sandspit, and terminate at a river-mouth. The beach surface slopes upward at an angle of a few degrees and steepens suddenly at the foredune. This is 50 to 100 feet wide, and is commonly 15 to 30 feet high, and in a few cases more than 40 feet. The top of the beach is about 10 feet above low-water level, and thus the elevation of the foredune-crest with respect to water is 25 to 50 feet. The landward or leeward slope of the foredune is usually steeper than the seaward or windward slope, except during stormy weather and exceptionally high tides, when wave erosion at its base may convert the front of the dune to a vertical sand-cliff. A typical foredune runs the whole length of the beach, and maintains a uniform cross-section and crest-height over considerable distances. The foredune is formed during long spells of fine weather from sand blown up from the beach. Its surface soon becomes stabilized and protected from wind erosion by a growth of native grass such as coastal couch and *Spinifex hirsutis,* and creepers such as Goatsfoot Convolvulus.

During stormy weather, heavy minerals are deposited at the top of the beach, where they build up a "seam" commonly a foot or more thick, 30 to 50 feet wide, and running in some cases for more than half the length of the beach. In fine weather, the lower part of the seam is washed down the beach and is lost through admixture with quartz sand, but the upper part is covered by wind-blown sand. It may later be covered by the front half of the foredune, encroaching seaward during a long period of building.

Parallel Dunes.

In most beach areas, one or more sand ridges occur behind and parallel to the foredune. When mentioned later in this report, they will be termed "parallel dunes". They commonly overlie seams of heavy minerals, and are clearly earlier foredunes formed in succession during a period when the shoreline was advancing seaward. Such an advance may be attributed to shallowing of the off-shore water due to silting or a slight fall in the sea level or both. In two of the areas where the parallel dunes are well developed—at Broadbeach, Queensland, and Cudgen Beach, New South Wales—careful boring has indicated that the black sands beneath the more landward ones were deposited on beaches 1 to 2 feet above the present beach. Presumably the dunes were developed during a fall in sea level or an emergence of this magnitude. The parallel dunes are generally effectively stabilized by a covering of dune scrub, consisting of trees, shrubs, vines, and grasses. In many places the vegetation is dense enough to hinder progress on foot, and to make vehicle transport impracticable.

Coastal Plain.

The coastal plain forms a fringe of varying width to older consolidated rock. It is broken into discontinuous areas by spurs that extend to the coast to form headlands, and on its seaward side is fringed by beaches and beach dunes. Two distinct parts can be recognized in many coastal plains: a low-lying portion which starts at the landward edge of the beach dunes, and a more elevated portion some distance farther inland.

The low-lying part consists of broad sandy flats and swamps and narrow arcuate belts of swamps alternating with low sand ridges. The sandy flats are only a few feet above sea level, but the water-table is at a sufficient depth to allow a growth of swamp oak, rush-like sedges, and in the slightly more elevated parts, bloodwood, bracken and blady-grass. Their origin is illustrated in the area behind the beach dunes at Palm Beach, Queensland. There, tidal flats at the mouth of Tallebudgera Creek are seen to give place, landwards, to marine meadow and mangrove fringes, followed by large stands of paper-bark ti-tree, these in turn by swamp oak, and finally bloodwood, bracken, and blady-grass. The process of reclamation may in some places be due entirely to silting, aided by the accretion of wind-blown sand from the beach and dunes; in other places, it is undoubtedly due to the slight fall in sea-level, mentioned above in the description of the parallel dunes.

The narrow arcuate belts of swamp and low sand ridges curve around in the same way as do the parallel beach dunes. They appear to have originated, as the dunes did, through the silting of an earlier bay and a consequent seaward advance of the shoreline. Apparently each sand ridge represents a sand-spit or sand-bar that extended northward from the southern end of the bay at about the outer edge of the surf zone, enclosing on its landward side the former beach and a narrow strip of shallow water, now the swamp. The lowest of the sand ridges, which barely rise above swamp level, support little more than grasses and rush-like sedges. The higher ridges have coverings of *Banksia serratifolia* and heath-like shrubs, and some rise high enough above ground-water level to support mixed dune scrub.

Typical low-lying coastal plains are seen behind Broadbeach and Palm Beach, Queensland, and Cudgen Beach and other beaches from Potts Point to Byron Bay, New South Wales.

Heathlands.

The more elevated part of the coastal plain consists typically of heathland and swamp. Commonly, it displays in parts a pattern of arcuate belts of swamp and sand ridge similar to that seen in the low-lying coastal plain, but more or less obscured by erosion. At a slight depth below the surface, the sand is indurated and rendered impervious by organic matter which has been deposited from swamp-waters percolating through it. Heathland areas are seen in Queensland at North Burleigh and at Tugun, and in New South Wales 1 mile inland from Cudgen Beach, at Norries Head, at Tallow Beach, between Broadwater and Evans Head, and between Evans Head and Woody Head near the mouth of the Clarence River. Heathlands are known to occur farther south along the coast.

For some miles north and south of Evans Head, the heathland areas extend to the coastline, forming low sea cliffs of indurated sand. In the cliff faces the bedding planes appear horizontal, or are current-bedded, and have major planes of stratification which appear to be horizontal, although the bedding-planes actually dip seawards at a slight angle. The cliffs appear to be composed of beach sand or shallow-estuary sand, too coarse to be dune sand, and in places they contain pebble-beds. They are bay-floor deposits emerged presumably through lowering of the sea level in late Pleistocene or Recent times. Some of the heathlands contain heavy-mineral deposits, which are clearly former beach seams. Such a seam occurs between Evans Head and Woody Head, beneath a narrow belt or low ridge of sandy heathland that curves around approximately parallel to the beach and ¼ to ⅓ mile from it. Others are known to occur at North Burleigh, near Norries Head, near Seven Mile Beach, and between Evans Head and Broadwater, at distances of a few hundred feet, half a mile, 1¼ miles, and 2 to 3 miles, respectively, from the present beaches.

The seam between Evans Head and Woody Head, mined for gold towards the end of the 19th century, when it was named Macaulays Lead, is 10 feet above the seams on present-day beaches. Those near Broadwater and Norries Head are probably at the same level as Macaulays Lead. The seams near Seven Mile Beach and at North Burleigh were estimated, as a result of boring, to be 5 feet above present beach-seams. The heathlands apparently represent typical coastal areas, comprising tidal flats and the floors of shallow bays, littoral deposits and beach dunes, which have emerged, some a total of 10 feet and others 5 feet, above sea level. Other heathlands occur south of Evans Head at higher levels. They have not been examined in detail. They possibly originated in the same way as those just described, through emergences of greater magnitude. They will be mentioned in the section on general geology when eustatic changes in sea level are discussed.

Evidence of late Submergence.

The beach-seams at 10 feet, 5 feet, and 2 feet above sea level seem to indicate successive net emergences of 5 feet, 3 feet, and 2 feet. Before the latest emergence, the coastal area was probably submerged to at least 5 feet below present sea level. The evidence for this is the occurrence of peat deposits and mineral-seams below present sea level. On beaches north and south of Evans Head, peat deposits containing mangrove stumps and roots extend from about high-water level to some depth below low water. It seems likely that the peat started to form during an interval when the sea level was somewhat lower than it is at present. The lower limit in depth of these deposits is not known. At North Burleigh and Tugun, deposits of heavy minerals continue downwards to at least 2 feet below low-water level. The lower limit of present-day beach seams is, approximately, mean sea level, which is 3 feet above mean low water. Hence the low-level seams indicate a sea level at least 5 feet below its present level.

Transgressive Dunes.

Parts of the coast are fringed by dunes which are quite distinct from the beach dunes, in that they are elongated in the direction of the prevailing wind. They have obviously developed as active dunes moving in that direction, and are referred to here as transgressive dunes. They are best developed on the sandy islands off the south coast of Queensland, and are described in the section dealing with North Stradbroke Island. There it is shown that they occur in five distinct formations that developed in successive stages, the dunes of each stage advancing partly across those of the preceding stage. Their surfaces are effectively stabilized by a covering of vegetation, which varies from place to place, ranging from rain-forest to heath-like shrubs. Minor transgressive dunes are forming to-day on a small scale through wind-erosion of beach dunes and are seen best on North and South Stradbroke Islands. The foredune and parallel dunes are being broken up by blowouts and converted into active transgressive dunes. Probably the older transgressive dunes were formed in the same way, but it is obvious that much larger quantities of sand must have been available than those that occur in the present-day beach dunes. This could have been provided only by an uplift of the coastal area, or a fall in the level of the sea, at each stage of dune-building. The transgressive dunes on the mainland are best developed on the south coast of Queensland, from Double Island Point to 6 miles south of Noosa Head. For some miles south of Double Island Point they rise to heights exceeding 600 feet. The dunes have not been examined in the field, but the contour-lines and drainage patterns shown on military maps suggest that they have developed in several stages.

Military maps indicate also that new transgressive dunes occur along portions of the New South Wales coast for about 20 miles south from the mouth of the Clarence River and for 10 miles southward from Sugarloaf Point opposite Myall Lake. A dune stretch behind Newcastle Bight, more than 12 miles long and a mile or so wide, probably consists of beach dunes being converted to transgressive dunes. Similar smaller areas occur at Nine Mile Beach, just north of Lake Macquarie, and at Tuggerah Beach on the seaward side of Tuggerah Lake.

Irregular dune masses which are probably eroded remnants of transgressive dunes, mentioned later in the descriptions of the individual areas, occur near Cudgen Head, Tallow Beach, Ballina at the mouth of the Richmond River, Broadwater north of Evans Head, and for some miles south of Evans Head. Even where best developed, the transgressive dunes in New South Wales are much smaller than those in Queensland, and they seem to have developed in only one or two stages.

Sandy Islands.

The large sandy islands off the south coast of Queensland—Frazer, Moreton, and Stradbroke Islands—seem to be made up almost entirely of old transgressive dunes, stabilized by a covering of vegetation. The dunes rise to a maximum height of 900 feet, and are elongated in a north-north-westerly direction. North Stradbroke and South Stradbroke Islands existed as a single unit until 50 years ago, when tidal currents in the Broadwater opened a passage at Jumpinpin. The opening between South Stradbroke Island and the mainland was probably made in the same way at some earlier period, and if so, it became the first break in a long beach that extended from Burleigh Head to Point Lookout. Similarly, Moreton Island may have been joined to North Stradbroke Island, and Frazer Island to the mainland at Inskip Point.

Frazer and Moreton Islands have not been examined in the field, but some information on them is given by Connah (1948) and Morton (1948). North Stradbroke Island was examined in greater detail during reconnaissance surveys by a Bureau party in January, 1948.

The north-eastern corner of each island is formed of consolidated rock which rises to a height of one or two hundred feet: presumably it acted as a barrier to northward migrating sand.

The area of transgressive dunes terminates on the east as an abrupt scarp or cliff. On Frazer Island and the greater part of Moreton Island, the cliff overlooks the ocean beach; on North Stradbroke Island it is obviously a former shoreline, but is now separated from the ocean by a narrow belt of swamp and beach dunes. This low-lying tract is comparable with the low-lying portions of the coastal plain fringing the mainland and undoubtedly it originated in the same way.

On North Stradbroke Island seams of heavy minerals occur on the ocean beach and beneath the parallel dunes, and very large tonnages exist in low-grade deposits in the transgressive dunes.

At several localities along the eastern, western, and northern sides of the island, deposits of sand-rock, practically horizontally-bedded or with a slight seaward dip, are exposed in creek beds and in the scarp at the edge of the transgressive-dune area. Carbonaceous material deposited between the grains has bonded the sand, and given it a brownish or chocolate colour. The deposits, which will be referred to later as organically-bonded sand-rock, are clearly water-laid. They occur at heights of 30 to 60 feet and 90 to 110 feet above sea level, and probably were deposited in coastal swamps, such as those that occur in the low-lying parts of coastal plains.

GEOLOGICAL BACKGROUND.

General.

The country drained by the eastward-flowing streams, and contributing sediment to the coast, is underlain by sedimentary and igneous rocks of the Palaeozoic Tasman Geosyncline, and marginal, Mesozoic, freshwater basins. It is covered in places by remnants of Tertiary basalt flows, some of which occupy considerable areas. The main divide runs south-east along the basalt-covered Bunya Mountains of southern Queensland through country underlain by Jurassic freshwater sediments, and turns south near the latitude of Brisbane. The Moreton Basin of Triassic and Jurassic sediments extends from this portion of the divide towards the coast, near which intervenes a narrow belt of Lower Palaeozoic sediments. The divide continues southwards towards the headwaters of the Hunter and Goulburn Rivers, following the relatively high New England Plateau. Most of this country is underlain by Permian granitic rocks, which form a roughly elliptical area more than 80 miles wide and 200 miles long.

From the northern part of the New England area, the Clarence Basin of Jurassic sediments stretches towards the south-south-east, widening as it approaches the coast.

The remainder of the country east of the divide is underlain by Palaeozoic sediments—Ordovician and Silurian southwards to the basalt-capped divide between the Macleay and Hastings Rivers, and Devonian and Carboniferous from there to the Hunter River. The Hunter-Goulburn valley marks approximately the northern edge of the triangular Permian sedimentary basin that contains the main coal-fields of New South Wales. It is capped by the resistant Triassic Hawkesbury Sandstone. The divide bulges out around the Hunter-Goulburn headwaters and swings in again to follow, approximately, the western edge of the Permian basin. As noted in the section on physiography, the New England area gained much of its altitude from Tertiary upwarping, which also elevated the western portions of the marginal basins and tilted them to the east.

SOURCES OF SAND AND HEAVY MINERALS.

General.

The sand along the coast consists essentially of quartz, and its main sources must be granitic rocks and arenaceous sedimentary rocks derived from them. The heavy minerals are accessory minerals of the same rocks, and may also include accessory minerals of basic volcanics and intrusives.

The principal areas which may be considered as possible sources of sand and heavy minerals are the New England granitic rocks, the Mesozoic basins of sedimentary rocks, the Ordovician and Silurian rocks between the Clarence Basin and the Macleay-Hastings divide, the Devonian and Carboniferous rocks between there and the Hunter River, the Permian and overlying Triassic rocks of the Permian sedimentary basin, the remnants of basalt throughout the area, and Tertiary river-gravels exposed by erosion of the basalt. Later, it will be shown that nearly all the sand along the coast was deposited during and after the late Pleistocene, and much of it in early Recent and mid-Recent times. This means that it was derived during only a brief period of erosion. A discussion of the relative amounts of sand and heavy minerals that may have been contributed by the several areas is given below.

SAND.

Mesozoic Basins.

The sediments of the Mesozoic basins contain a large proportion of comparatively soft sandstones, and undoubtedly they have contributed the largest quantities of sand to the coast, via the Clarence-Richmond and the Brisbane-Logan-Albert river systems. The deep dissection of their slopes where they rise towards the highlands had been mentioned in the section on physiography.

The New England Plateau.

Erosion at the eastern margin of the New England Plateau has developed precipitous scarps and deep gorges. However, on the surface of the plateau, the streams flow sluggishly in the valleys that have been little eroded since the Tertiary. It seems that the New England area as a whole is contributing directly only a small proportion of the sediment that reaches the coast.

Ordovician and Silurian Sediments.

The Ordovician and Silurian sediments between the Clarence Basin and the Macleay-Hastings divide, strongly folded and resistant to erosion, form a high plateau, which has been somewhat dissected on the seaward slope by the Bellingen, Nambucca, and Macleay Rivers. They are made up mainly of fine-grained sediments characteristic of deep geosynclinal conditions, with interbedded spilites and other volcanics. They are poor in arenaceous material, and presumably for this reason the sand deposits on this part of the coast are relatively small.

Devonian and Carboniferous Sediments.

Although the Devonian and Carboniferous rocks farther south rise to higher altitudes, they have been eroded more widely than the Ordovician and Silurian farther north. In their lithology, the Devonian rocks resemble the Silurian and Ordovician, and cannot be expected to yield much sandy sediment. The Carboniferous beds differ from the earlier Palaeozoic in containing a notable proportion of arenaceous and coarser-grained sediment in marine beds, terrestrial lacustrine sediments deposited in piedmont areas, and glacial and fluvio-glacial deposits. The areas underlain by Carboniferous rocks are drained principally by the Hastings, Manning, and Hunter Rivers, which undoubtedly have provided the sandy deposits between the Hunter and the Macleay Rivers. These are considerable, although much less extensive than the deposits between the Clarence River and Frazer Island. Besides the main rivers, many smaller streams such as the Myall and Karuah Rivers flow to this section of the coast. They enter lakes or indentations which have not been silted, and thus they can carry only minor amounts of sediment.

The sand in the near North Coast does not appear to have undergone the extensive migration seen north of the Clarence River. Spits between the Hunter and the Bellingen Rivers have developed both to the north and the south, although the northerly directed ones are the more prominent. Probably, long-shore currents and winds are directed successively northwards and then southwards in different seasons of the year, resulting in alternate northward and southward shifting of sand in the littoral zone.

Main Coal Basin.

The area south of Newcastle capped by Triassic Hawkesbury Sandstone has an indented coast that has not been markedly silted. Apparently the resistant sandstone cover has prevented much erosion. Sand deposits do occur, such as that on and behind Tuggerah Beach, and deposits of heavy minerals are being worked south of Swansea.

Tertiary Basalt and River Gravels.

Most of the areas covered by basalt are small, the largest generally occurring at the headwaters of streams, and forming the divides. They cannot have contributed much sediment to the streams, and in any case little of this would consist of sand. The basaltic area around and south of the Macpherson Range may have contributed some heavy mineral to the Richmond River, and this will be discussed later. The Tertiary river-gravels buried by the basalts undoubtedly contribute some sand and heavy minerals to the present-day streams. However, they form only small areas, which are being exposed and eroded at a slow rate, and the quantities of sediment yielded by them can only be small.

HEAVY MINERALS.

The heavy minerals of commercial interest in the beach sands, in order of abundance, are zircon, rutile, ilmenite, and a very small proportion of monazite. Others occurring as minor constituents include garnet, tourmaline, leucoxene, chromite, epidote, spinel, magnetite, and cassiterite. The suite of minerals is typical of those found in granites and surrounding metamorphics, except that rutile occurs in much smaller proportions in such a provenance. The chromite, ilmenite, and magnetite could be derived in part from basic igneous rock. Arenaceous sedimentary rocks should contain the same stable heavy minerals as the igneous rocks from which they were derived, except that ilmenite may be altered wholly or in part to leucoxene, anatase, brookite and rutile.

Samples of rocks and stream sands collected by the Bureau party from the New England area and the Clarence Basin were examined by Beazley (1950), who concluded that the beach-sand heavy-mineral deposits of southern Queensland were derived from the New England granites via the Clarence sandstones. The Bureau's work, as shown below, supports his main conclusions.

New England Granites.

It has been pointed out that the New England area cannot have contributed much to the deposits of sand along the coast; and for the same reasons, little of the heavy mineral can have come directly from it. However, it was the source of the sediments and heavy minerals of the Clarence Basin. The New England granite may be regarded as a composite batholith emplaced in a series of successive intrusions (David, 1950): firstly of porphyrite followed by quartz diorite-porphyrite; later of porphyritic hornblende-biotite granite; and towards the end coarse-grained acidic orthoclase granite. Associated with this last stage are numerous dykes of aplite, pegmatite, and quartz, and areas of marginal greisenization, some of which contain deposits of tin, wolfram, bismuth, and molybdenite. Monazite occurs in hydrothermal and pegmatitic deposits and as a rare constituent of the granitic rocks. Gold ores are found at several localities within the New England area.

The granitic rocks were examined by Andrews (1905), who classified them as grey and black felspar porphyries, blue granite, sphene granite-porphyry (and sphene diorite-porphyry), and coarse acid granite or tin granite.

Beazley (1950) broke samples of granite down to monomineralic particles, and made estimates of the relative abundance of the heavy minerals. Table 1 below is based on his Table IV., omitting all except zircon, monazite, magnetite and the titaniferous minerals.

TABLE 1.—HEAVY MINERALS IN NEW ENGLAND GRANITIC ROCKS.
Adapted from Beazley (1950).

Rock Type.	Zircon.	Rutile.	Ilmenite.	Monazite.	Leucoxene.	Magnetite.	Sphene.	Anatase.
Coarse-grained acid granite, New England Highway, north of Tenterfield ..	C	S	S	S	..	C	S	S
Coarse-grained granite, Stanthorpe ..	C	..	S	..	..	C	S	S
Pegmatite, north-east of Tenterfield ..	C	S	S	S	..	C	..	..
Sphene granite-porphyry, near Wallongorra	s	..	S	..	S	s	C	..
" Basic " blue granite, 2 miles east of Tenterfield	s	S	s	..	..	s	S	S

C = very common ; s = scarce ; S = very scarce.

Table 1 shows that all the beach-sand minerals are present in the New England granites, but a quantitative estimate cannot be made from it. A better idea of their relative amounts may be had from the analyses of stream sands shown here in Table 2, adapted from Beazley's Table VII.

TABLE 2.—ZIRCON, MONAZITE, MAGNETITE, AND TITANIFEROUS MINERALS IN NEW ENGLAND STREAM SANDS.
Adapted from Beazley (1950).

Stream.	Zircon.	Monazite.	Magnetite.	Rutile.	Ilmenite.	Leucoxene.	Sphene.	Anatase.
Mann River on road from Glen Innes to Grafton, 78½ miles from Grafton ..	5.2	0.6	72.1	2.1	5.7	..	2.4	..
	(Contained 10.1 per cent. hornblende)							
Bluff River, between Tenterfield and Glen Innes	18.0	0.9	42.9	1.1	32.7	..	1.5	0.1
Sandy Creek, in granite country, between Tabulam and Tenterfield	10.0	1.0	11.8	3.5	63.8	..	3.5	..
	(Contained 5.5 per cent. hornblende).							
Average	11.1	0.8	42.3	2.2	34.1	..	2.5	..
Average calculated to percentages ..	11.9	0.9	45.5	2.4	36.7	..	2.7	..

Although the samples taken from the three streams differ widely in the proportions of their constituent minerals, Table 2 gives the best approximation, with the data available, to the average composition of the heavy minerals in the New England stream-sands. The average composition of the beach sand deposits from Ballina to North Stradbroke Island is:

Zircon.	Rutile.	Ilmenite.	Monazite.
40.6	31.6	27.3	0.5

No sphene has been found in the deposits, and magnetite amounts to much less than 0.1 per cent. Hence it seems that only a very small proportion of the beach-sand heavy minerals could have come directly from the New England granites. On the basis of percentage of magnetite—assuming on the one hand that no magnetite entered the beach sands from any other source, and on the other hand that none was lost from the New England heavy concentrates during transport—the beach sand deposits could not have received even 0.2 per cent. of their heavy minerals directly from the New England granites.

Clarence Basin.

The Clarence Basin, drained by the Clarence and Richmond River systems, is a structural and physiographic basin (David, 1950) that extends for 120 miles southwards from the Queensland-New South Wales border. Its maximum width is 65 miles. The surface is underlain by Jurassic sediments of the Upper Clarence and the Lower Clarence Series, the Upper Clarence occupying the full width of the basin on the north and tapering towards the south, and the Lower Clarence forming a continuous fringe around the western, southern, and eastern or coastal margins. The basin is tilted towards the east, the base of the Jurassic being at an altitude of more than 1,000 feet near Drake on the west, and at or below sea level on the coast, north of the Clarence River. Remnants of Tertiary basalts occur in places throughout the basin and form a large area in the north-east from Ballina to the Macpherson Range.

The Clarence strata consist of sandstone and a little conglomerate, sand-stone, and shale with thin coal bands. At Glenreagh near the southern end of the Basin flows of basic lava are interbedded with the sediment. The sandstones form a considerable proportion of the total thickness of sediments, and are generally relatively soft and easily eroded. Samples examined by Beazley (1950) contained 0.7 to 1.5 per cent. heavy minerals. The compositions of their heavy-mineral suites are given in Table 3, which is adapted from Beazley's Table IV.

TABLE 3.—HEAVY MINERALS IN CLARENCE SERIES SANDSTONES.

Adapted from Beazley (1950).

Locality.	Zircon.	Rutile.	Ilmen-ite.	Mona-zite.	Leuco-xene.	Sphene.	Other Minerals.
Outcrop near Yamba	33.1	14.0	10.1	3.2	8.8	..	Garnet 27.5 Tourmaline 2.9
Road cutting near Tabulam ..	29.0	37.9	22.4	6.1	1.4	..	Garnet 0.9 Tourmaline 2.0
Road cutting near Broken Head ..	21.5	20.0	11.3	1.2	41.0	0.3	Garnet 1.2 Tourmaline 2.3 Epidote 9.4 Spinel 0.5

Neglecting the "Other Minerals", the composition recalculated to per-centages is given in Table 4.

TABLE 4.—ZIRCON, RUTILE, MONAZITE, AND TITANIFEROUS MINERALS IN CLARENCE SERIES SANDSTONES.

Locality.	Zircon.	Rutile.	Ilmenite.	Monazite.	Leucoxene.	Sphene.
Outcrop near Yamba	47.8	20.2	14.6	4.6	12.7	..
Road cutting near Tabulam ..	30.0	39.2	23.1	6.3	1.4	..
Road cutting near Broken Head ..	22.6	21.0	11.9	1.3	43.0	0.3
Average	33.5	26.8	16.5	4.1	19.0	0.1

It may be assumed that the heavy minerals in the Clarence sandstones have been derived largely from those in the New England granites. Their compositions, as well as is known, are given in Table 2. Obvious differences are the disappearance of magnetite, and, virtually, of sphene, a reduction in the proportion of ilmenite, a large increase in the proportion of rutile, and the appearance of relatively large amounts of leucoxene. These changes are apparently caused by weathering and diagenesis. Since the sediments were deposited, the magnetite has weathered to hydrated oxides, probably through an intermediate stage of reduction, solution, and transport in ground-water. Some of the ilmenite has weathered to leucoxene and possibly other titanium oxides, and its iron content has probably followed the same course as that of the magnetite. David (1950) mentions ferruginous concretions in shales, and fossil stems and petrified wood preserved in ironstone, and considerable concentrations of iron, in places, in the massive siliceous sandstones of the Kangaroo Creek Stage. Beazley (1950) states that some of the rutile grains in the sandstones are euhedral or nearly so, and crystal edges usually can be seen. This suggests that the rutile is largely an authigenic constituent, formed by the alteration of ilmenite and sphene. Support for this suggestion is obtained from Table 5, which has been prepared from Tables 2 and 4 to show the relative proportions of zircon, monazite, and total TiO_2 in New England stream-sands and in Clarence sandstones. The average compositions shown are closer than might have been expected. The discrepancy in the proportions of monozite may be due to the fact that the New England samples came from typical granitic areas, rather than mineralized areas, which are richer in monazite, whereas the sandstones have received sediment from both.

TABLE 5.—ZIRCON, MONAZITE, AND TOTAL TiO_2 IN NEW ENGLAND STREAM SANDS AND CLARENCE SERIES SANDSTONES.

Locality.	Zircon.	Monazite.	Rutile.	Ilmenite.	Leucoxene.	Sphene.	Total TiO_2.
New England Stream Sands.							
Average of Table 2, omitting magnetite ..	21.8	1.6	4.4	67.2	..	4.9	..
	..	..	(4.4)	(31.0)	..	(2.7)	38.1
Calculated to percentage	35.4	2.6	..	..	..	..	62.0
Clarence Series Sandstones.							
Average of Table 4 ..	33.5	4.1	26.8	16.5	19.0 *	0.1	..
	..	..	(26.8)	(7.6)	(18.0)	..	52.4
Calculated to percentages	37.2	4.6	..	..	..	..	58.2

* It is assumed that Leucoxene is $TiO_2.nH_2O$, (Coil, 1933 ; Edwards, 1942) and that the quantity of water is small.

In addition to the heavy minerals in the Clarence sandstones some magnetite and ilmenite must be derived from overlying Tertiary basalts, andesites, and volcanics within the Clarence Series. The quantities cannot be large, because interbedded volcanics have been recorded only near the southern extremity of the basin, and the remnants of Tertiary lavas are small, except in the north-east. Samples from stream sands were examined by Beazley (1950). Their heavy-mineral compositions are given in Table 6, which is adapted from Beazley's Table VII.

TABLE 6.—HEAVY MINERALS IN STREAM SANDS IN CLARENCE BASIN.
Adapted from Beazley (1950).

Stream and Area Drained.	Zircon.	Rutile.	Ilmenite.	Monazite.	Magnetite.	Other Minerals.
Orora River, nine miles west of Grafton .. .. (Drains Clarence Series only)	43.7	19.0	21.7	5.5	0.2	Garnet 6.7. Leucoxene 1.3
Tributary of Richmond, between Tabulam and Casino (Clarence Series, and small remnants of basalt)	38.0	17.7	29.9	6.3	1.0	Garnet 6.3
Richmond River at Casino .. (Clarence sediments, near large area of Tertiary basalts)	4.8	4.2	60.9	0.7	20.2	Garnet 7.6 Augite 1.1

The compositions of Table 6 compared with those of the Clarence sandstones shown in Tables 3 and 4 are higher in zircon, monazite, and ilmenite, lower in rutile and leucoxene, and contain magnetite which was not found in the sandstones. The enrichment in zircon and monazite is readily understood: they are the heaviest of the minerals, and in addition, zircon occurs as quite large crystals (Beazley, 1950). As a result they tend to accumulate in the stream bed. On the other hand, leucoxene is the lightest of the minerals; it is readily transported downstream; and practically all of it is removed from the stream sands. The magnetite in the stream sands and the additional ilmenite apparently came from Tertiary basic volcanics, because both these minerals are more abundant in the samples taken from areas where the volcanics are more widespread. This is confirmed in a qualitative way by the mechanical analyses given in Table 7 of the concentrates of Table 6 together with one from Currumbin Creek. The latter flows through Lower Palaeozoic greywacke capped by Tertiary basalt. Its heavy minerals are nearly all derived from the basalt, and contain 86.4 per cent. ilmenite and 0.9 per cent. magnetite.

TABLE 7.—MECHANICAL ANALYSES OF HEAVY MINERALS IN STREAM SANDS IN THE CLARENCE BASIN AND IN THE MACPHERSON RANGE.
Adapted from Beazley (1950), Table V.

Locality of Sample.	Aperture Size of Sieve and Percentage Weight of Heavy Mineral Retained.						
	.251	.178	.152	.124	.104	.076	<.076
Clarence Basin—Orora River ..	22.2	40.8	14.8	5.3	3.4	12.7	0.7
Tributary of Richmond between Tabulam and Casino ..	3.2	21.6	17.0	10.4	0.9	44.1	2.7
Richmond River at Casino ..	..	5.0	8.8	8.5	2.1	67.4	8.2
Macpherson Range—Currumbin Creek	0.6	3.1	5.1	3.0	2.1	66.2	19.9

It can be seen that increasing proportions of ilmenite and magnetite in the samples are accompanied by similar increases in the proportions of the smallest two size grades. On the other hand, the ilmenite and magnetite in stream sands in the New England area are, in general, much coarser-grained. This is shown in Table 8, which gives the mechanical analyses of the heavy minerals of Table 2.

TABLE 8.—MECHANICAL ANALYSES OF HEAVY MINERALS IN STREAM SANDS IN THE NEW ENGLAND GRANITIC AREA.

Adapted from Beazley (1950), Table V.

Locality.	Aperture Size of Sieve and Percentage Weight of Heavy Minerals Retained.						
	.251	.178	.152	.124	.104	.076	< 076
Mann River	9.9	27.9	16.5	8.0	12.0	25.4	0.3
Bluff River	..	14.2	16.0	11.8	5.0	52.6	0.4
Sandy Creek..	7.2	40.4	20.4	10.1	0.3	21.5	0.1

Summarizing, the Clarence Basin sediments are made up in part of sandstones, which contain different proportions of the same relatively stable heavy minerals as the New England granitic rocks. The proportions of zircon, monazite, and total titania are nearly the same in the sandstones as in the New England stream sands. Remnants of Tertiary basic volcanics capping portions of the Clarence Basin contribute fine-grained ilmenite and magnetite to the stream sands.

Moreton Area.

The Triassic and Jurassic beds of the Moreton area comprise conglomerate, grits, sandstones of siliceous, felspathic, and ferruginous types, shales, carbonaceous shales, and coal seams. Intrusive rocks include alkaline dykes, plugs, and laccoliths, and sills of analcite-dolerite, probably early Tertiary in age. The younger of the Jurassic beds, those of the Walloon Series, occupy large areas in the west and south, and include a large proportion of very soft, easily weathered, calcareous sandstone. Tertiary basic volcanics cover the main divide on the west and the Macpherson Range on the south, and remnants of them occur within the area.

The heavy minerals in some of the sandstones are shown in Table 9, which is adapted from Beazley (1950), Table IV. The quantities of heavy minerals obtained by Beazley amounted to 0.1 per cent. or less from each sample compared with 0.7 to 1.5 per cent. from Clarence sandstones.

TABLE 9.—HEAVY MINERALS IN SANDSTONES OF MORETON AREA.

Adapted from Beazley (1950).

Locality.	Zircon.	Rutile.	Ilmenite.	Monazite.	Leucoxene.	Garnet.	Tourmaline.
Near Beaudesert (Bundamba sandstone)	32.2	14.9	10.8	2.4	5.5	32.6	1.1
Cape Moreton (U. Triassic) ..	31.9	15.7	18.5	2.8	6.8	20.1	3.9
Caloundra Head (U. Triassic) ..	8.2	14.2	10.0	2.3	2.3	58.8	3.8
Alexandra Headland (Jurassic) ..	4.5	4.0	2.8	1.7	0.4	85.4	1.2
Point Arkwright (Jurassic) ..	32.5	40.5	18.7	3.5	0.4	2.8	1.5
Average	21.9	17.8	12.2	2.5	3.1	39.9	2.3

These sandstones differ from those of the Clarence Series (Table 3) mainly in their large garnet content. A better comparison of the compositions may be got by calculating the relative percentages of zircon, monazite, and titanium minerals, as is done in Table 10, and referring to the corresponding Table 4 for the Clarence sandstones.

TABLE 10.—ZIRCON, MONAZITE, AND TITANIFEROUS MINERALS IN SANDSTONES IN MORETON AREA.

Locality.	Zircon.	Rutile.	Ilmenite.	Monazite.	Leucoxene.
Near Beaudesert	48.9	22.6	16.4	3.6	8.4
Cape Moreton	42.1	20.7	24.4	3.7	9.0
Caloundra Head	22.3	38.0	27.2	6.2	6.2
Alexandra Headland	33.6	29.8	20.7	12.7	3.0
Point Arkwright	34.0	42.4	19.6	3.7	0.4
Average	36.2	30.7	21.7	6.0	5.4

It can be seen that the Mesozoic sandstones of the Moreton area contain the heavy minerals of the beach sands in much the same proportions as the sandstones of the Clarence Basin, except that they have an appreciably larger proportion of monazite and much less leucoxene. It has already been noted that the proportion of heavy minerals is only about one-tenth of that contained in the Clarence samples.

In addition to the sediments, the Mesozoic strata of the Moreton area contain a considerable thickness of volcanic rocks, both acidic and basic. Through much of its course, the Brisbane River flows through Upper Triassic rocks of the Esk Series, of which the lower stage consists predominantly of andesitic rocks. Their heavy minerals appear to be represented in the sands of the Stanley River at Somerset Dam. These have the composition given in Table 11, which was adapted from Beazley (1950), Table V. Magnetite, hornblende, and sphene are hardly represented at all in beach sands, and hence Table 11 shows also the percentage composition when these are omitted.

TABLE 11.—HEAVY MINERALS FROM STANLEY RIVER.

Adapted from Beazley (1950).

Zircon.	Rutile.	Ilmenite.	Monazite.	Magnetite.	Sphene.	Garnet.	Hornblende.
1.5	..	40.6	0.8	46.7	0.8	0.9	5.0
(3.5)	..	(94.6)	(1.7)	..	..	..	..

A mechanical analysis of these heavy minerals shows that 93.4 per cent. by weight of them consist of grains larger than 0.178 mm.; the ilmenite and magnetite grains here are much larger than those derived from the Tertiary volcanics in the Clarence area.

A sample of Brisbane River sands from Moggill, about 20 miles west-southwest of Brisbane, examined by Beazley (1950), yielded only a small amount of heavy concentrate, and this can hardly be regarded as representative of the heavy minerals being transported by the river. However, the composition, given in Table 12, is of the type that could be expected from a mixture of heavy minerals from the Mesozoic sandstones (Tables 9 and 10) and from the andesitic rocks.

TABLE 12.—HEAVY MINERALS FROM BRISBANE RIVER.

Adapted from Beazley (1950).

Zircon.	Rutile.	Ilmenite.	Monazite.	Magnetite.	Sphene.	Garnet.	Hornblende.
6.5 (24.4)	5.5 (20.7)	13.7 (51.5)	0.9 (3.4)	25.1 ..	2.7 ..	2.7 ..	35.2 ..

Ordovician and Silurian Sediments.

Little is known of the heavy-mineral suites of these rocks, and no samples have been obtained from streams flowing over them. Samples of Silurian greywackes from south-east Queensland, examined by Beazley (1950), contained generally less than 0.01 per cent. by weight of heavy minerals. These, in their order of abundance, were zircon, ilmenite, leucoxene, and tourmaline, and their grain-size is much smaller than that of the beach-sand minerals. The Ordovician and Silurian sediments drained by the Macleay, Nambucca, and Bellingen Rivers probably have similar heavy-mineral assemblages, and cannot be expected to have contributed much to beach-sand deposits.

Production has been recorded from the Woolgoolga area, on a stretch of coast formed by lower Palaeozoic sediments: but it is likely that this deposit came from Jurassic sediments of the Clarence Basin, which runs north-eastwards from its southern extremity, about 9 miles west-south-west of Woolgoolga, and meets the coast 9 miles northward from Woolgoolga.

Devonian and Carboniferous Sediments.

As far as is known, no work has been done on the heavy minerals of these rocks. The Devonian sediments are fine-grained, and probably they, like the Ordovician and Silurian, have only a very small heavy-mineral fraction. Besides, they occur as plateau areas which have not been greatly eroded. The Devonian strata contain relatively large proportions of basic volcanics and intrusives, which may be expected to yield ilmenite and magnetite.

The Carboniferous beds are in part made up of coarser sediments, which probably have an appreciable content of heavy minerals. They must have derived heavy minerals from the Devonian granites and granodiorites similar to those which the Clarence sediments derived from the New England area. In addition the Devonian basic igneous rocks undoubtedly contributed much ilmenite, which would be partly altered, in the Carboniferous sediments, to leucoxene and rutile. The Upper Carboniferous sediments obtained heavy minerals from erosion of Carboniferous granitic rocks. Probably their monazite content was relatively high, because they contain the same suite of metalliferous deposits—tin, tungsten, molybdenum, and bismuth—as do the Permian granites of the New England area. Beach-sand heavy-mineral deposits are known to occur at several localities between the Macleay and Manning Rivers and these were probably derived largely from Carboniferous rocks.

Permian Sediments of Coal Basin.

Within the coal basin the Permian sediments are covered by Triassic sandstones, but they crop out in a narrow belt around the basin, except along the coastal stretch from Newcastle to Coal Cliff. They consist of conglomerate, sandstone and tuffaceous sandstone, shale, coal seams, mudstone, chert, limestone, tuff and basalt. Carroll (1940) found that the principal heavy minerals of some sandstones and a tillite were zircon, leucoxene, ilmenite, and tourmaline. Small amounts of sphene, rutile, and monazite were present. The average composition, excluding scarce minerals such as epidote and chlorite, is given in Table 13.

TABLE 13.—HEAVY MINERALS FROM SOME PERMIAN SANDSTONES AND A TILLITE, MAIN COAL BASIN, NEW SOUTH WALES.
Adapted from Carroll (1940).

Zircon. %	Rutile. %	Ilmenite. %	Monazite. %	Leucoxene. %	Anatase. %	Sphene. %	Tourmaline. %
29.5	2.7	17.6	0.4	29.6	1.1	2.8	16.4

Culey (1938) found that the Upper Coal Measures and Upper Marine sandstones contained an average of about 0.02 per cent. heavy minerals. Of these zircon was by far the most abundant; anatase contributes more than 10 per cent., and picotite and tourmaline probably less than 10 per cent. Rutile apparently amounted to a few per cent. at the most; ilmenite much less than 1 per cent.; and monazite was apparently about 0.5 per cent. Culey states that leucoxene, limonite, and hematite frequently occur, and that there is very little fresh ilmenite.

The Permian strata that contributed sediments to the coast are mainly those drained by the Hunter-Goulburn Rivers. As noted before, the Hunter and its tributaries drain large areas of Carboniferous rocks, from which much of their sediments must be derived. Black-sand deposits may occur on the crest between the Hunter and the Manning Rivers. Carne (1911) recorded beach-sand accumulations near Seal Rocks. Any that do occur presumably derived their heavy minerals from the Permian and Carboniferous sediments brought down by the Hunter River.

Triassic Sediments of Coal Basin.

In discussing the sources of the sand along the coast, it was pointed out that relatively small quantities of sediment are being eroded from the Triassic rocks. These comprise principally the Hawkesbury Sandstone, which covers almost the entire basin, and two narrow strips of Narrabeen Sandstone, one at the south-eastern edge of the basin, and the other forming the coastal belt from Lake Macquarie to Collaroy, about 12 miles south of Broken Bay. David

(1950) states that the accessory minerals of the Hawkesbury Sandstone include zircon, rutile, ilmenite, magnetite, and others, but he gives no indication of their relative abundance. Culey (1932) found that the Narrabeen beds (principally sandstones) contain approximately 0.04 per cent. heavy minerals. Her tables 1 and 2 show that they are made up predominantly of zircon, with about 15 per cent. picotite, 10 per cent. each of tourmaline and ilmenite, about 5 per cent. each of anatase and rutile, less than 5 per cent. magnetite, and less than 0.5 per cent. monazite. Leucoxene was present, but its quantity was not estimated. Despite the apparent lack of erosion of the Triassic rocks, and the low heavy-mineral content of the Narrabeen sediments indicated by Culey's work, appreciable deposits of heavy minerals occur on beaches a little south of Swansea. They are richer in monazite and rutile than were the specimens examined by Culey, and this suggests that the deficiencies in these minerals, and in the total bulk of heavy minerals, may have been made up from sediments derived from the Hawkesbury Sandstone.

Coastal Area: Effects of Eustatic Changes in Sea Level.

General.

At various localities around the Australian coast raised littoral and estuarine deposits and erosion-surfaces attributed to eustatic changes in sea level occur at heights of approximately 100, 50, and 20 feet above sea level. These are noted by David (1950, Ch. XIII.), who gives an extensive bibliography. Evidence is found also of similar deposits and erosion-surfaces up to about 15 feet above sea level. These, however, are within the range of tides and of weathering related to ground-water level, and it is difficult to prove that they could not have been formed by processes acting during the period of the present sea level. In sheltered localities on limestone coasts, solution takes place above the zone of permanent saturation and deposition below it, with the result that a hard and resistant band is developed at mean low-water level. Along the limestone coast of Western Australia south of latitude 28° (Teichert, 1946; Fairbridge, 1948), hard bands of this type, and other criteria such as emerged shell-beds and erosion-surfaces, provide evidence that the sea formerly stood at 10 feet, 5 feet, and 2 feet above its present level. It is not unlikely that other raised beaches, river terraces, and wave-cut platforms around the Australian coast are referable to these levels. The raised beaches and other criteria mentioned above provide evidence of emergence of the coastline. Other evidence is available of deep submergence. Boring has revealed valley-in-valley structure below present-day valley floors, forests buried beneath estuarine flats and swamps, and sand dunes beneath present-day sand spits, all at considerable depths below present sea level. The land-surfaces which they represent may be correlated with the Pleistocene glacial extremes of low sea level. Table 14 summarizes the eustatic movements since mid-Pleistocene for which evidence has been obtained in Australia. The Pleistocene is based on Table 1 of Browne (1945), and the Recent on the observations of Teichert (1946) and Fairbridge (1948) in Western Australia.

TABLE 14.—EUSTATIC MOVEMENTS SINCE MID-PLEISTOCENE.

Epoch.	Duration.	European Sub-Division.	Eustatic Movements.	Level of Sea with Respect to Present Level. (ft.).
				*
Later Recent ..	2,000 years ..	.. .. ..	Emergence of 2 ft. ..	0
	Few centuries ..	.. .. ..	Emergence of 3 ft. ..	+ 2
			†	†
Mid-recent ..	Few centuries ..	.. .. ..	Emergence of 5 ft.	+ 5
Earlier Recent ..	1,000 years ..	.. .. ..	Emergence of 10 ft.	+ 10
Late Pleistocene ..	About 23,000 years	Würm Recession ..	Submergence of about 270 ft.	+ 20‡
		Würm Glacial ..	Emergence of about 295 ft.	— 250
		Riss-Würm Interglacial	Submergence of 295 ft. (?)	+ 45
		Riss Glacial ..	Emergence of 350 ft. (?)	— 250 (?)
Middle Pleistocene	About 185,000 years	Mindel-Riss Interglacial	Submergence ..	+ 100

* Gutenberg (1941) has shown that the sea has been rising during the last century, and at present the rate of rise is about 10 cm per century. Hence, strictly speaking, the sea is a little higher now than at the end of the 2-foot emergence. † The beach sand investigation indicates an emergence here resulting in a sea level at least 5 feet below its present level. Fairbridge (1948) has evidence of a sea level 10 to 20 feet below its present level. ‡ Teichert and Fairbridge have evidence of an emergence resulting in a sea level 30 feet below its present level. The p20 transgressive dunes on Stradbroke Island suggest an emergence greater than 10 feet and if so, a subsequent submergence must have brought about the + 10-foot sea level.

Carbonaceous Sand-rock, and Heathlands.

The outcrops of organically-banded sand-rock of North Stradbroke Island, occurring at 90 to 110 feet and 30 to 60 feet, are thought to represent deposits of the Middle and Late Pleistocene seas, which stood at +100 feet and +45 feet, respectively. On the mainland south of Evans Head at about 50 feet above sea level, high-level flats, made up of heath and swamp, are possibly to be correlated with the +45-foot sea level.

The heathlands at +10 feet and +5 feet can clearly be correlated with the +10-foot and +5-foot seas. Heathlands at +20 feet have not been proved. Some flat areas south of Evans Head have an elevation intermediate between that of the +10-foot heathland and that of the high-level flats which possibly correlate with the +45-foot sea. These may be contemporaneous with the +20-foot sea, but no evidence is available other than their general elevation and their occurrence in suitable localities. A relatively flat tree-covered sandy area near Broadwater, north of Evans Head, appears to be higher than the +10-foot heathlands and may have originated at the time of the +20-foot sea. Remnants of +20-foot deposits could be expected on North Stradbroke Island. However, it appears that the coastlines of the +45-foot and +10-foot seas were substantially the same. Hence the remnants of +20-foot deposits would be small, and probably covered by scree and later dunes. The low-lying coastal plain, and the parallel dunes adjacent to present-day beaches, some of which overlie mineral deposits that appear to be 1 or 2 feet above present beach seams, were formed during and since the time of the +2-foot sea.

Transgressive Dunes.

Each of the five stages seen where the transgressive dunes are best developed makes it necessary to postulate a rather abrupt onset of special conditions: a large accession of sand, and probably a great increase in wind-velocity. Both these conditions applied during the glacial stages of the Pleistocene. It is considered that the successive dunes stages developed during the recessions of the sea from the +100-foot, +45-foot, +20-foot, +10-foot, and +5-foot levels. The recession from the +2-foot sea level resulted in the formation of the parallel dunes. At the start of each recession, large quantities of sand were exposed along the shoreline, and parallel dunes were formed. At a later stage, the supply of sand diminished, and the building of parallel dunes ceased. The existing dunes became dissected by blowouts and converted to transgressive dunes. The process was probably accelerated by increase in the velocity and persistence of on-shore winds as the glaciation progressed and oceanic temperatures decreased.

The dune-stages may be named post-100, post-45, &c., or for brevity p100, p45, to relate each to the recession which accompanied or preceded it. The original outlines of the p100 dunes are not preserved. The loose surface sand has been removed from their higher parts and the exposed indurated sand is partly dissected, giving them a somewhat rougher relief than would be expected of dunes. The vegetation on the indurated surface is mainly heath and shrubs. The p45 dunes are generally well preserved, and covered with tall timber and undergrowth. They are eroded in places by drainage from the p100 surface. The p20 dunes are well preserved, and intermediate in mass between the earlier and the later stages. The p10 and p5 dunes are both distinctly developed along parts of the island, but in other parts only one dune-stage can be clearly seen. The magnitude of the dunes of each stage appears to be related to that of the recession to which it owes its origin. In the case of the p100 and p45 dunes, which are by far the most massive, the recession was of the order of 300 feet. The 100-foot sea level, and probably also the 45-foot sea level, persisted long enough to allow extensive sedimentation along the coast before the recession.

For the p20 dune-stage, the recession was only 10 feet, if the sea receded directly from +20 to +10 feet. However, Teichert and Fairbridge, as a result of their observations in Western Australia, considered that the sea receded from +20 feet to about −30 feet. This 50-foot recession appears to explain better the magnitude of the dunes than does a minor recession of 10 feet.

The recession that resulted in the formation of the p10 dunes was from +10 to +5 feet. The succeeding recession, which gave rise to the p5 dunes, has been regarded as simply from +5 to +2 feet. But a sea level at least as low as −5 feet must be assumed to account for the low-level seams of heavy minerals which succeeded the +5-foot seams. Teichert and Fairbridge in Western Australia found evidence of a comparatively recent sea level of −10 to −20 feet. In this report the low-level sea will be referred to as the −5(?)-foot sea. Bores put down during the beach sands investigation did not get to the bottom of the deposits, but it was thought that they were close to bottom. It can be seen that the recession from the +5-foot sea amounted to at least 10 feet, and it began with a coastline already silted as a result of the preceding recession of the sea from the +10-foot level. On the other hand, the +10-foot sea must have begun with a coastline that had little sediment along it, because it was initiated as a result of a submergence of 40 feet. A summary of eustatic movements and resulting sand deposits along the coast is given in Table 15.

TABLE 15.—EUSTATIC MOVEMENTS AND RESULTING SAND DEPOSITS.

Epoch.	Chronology (Years).	European Subdivision.	Eustatic Movement	Level of Sea, related to Present Level.	Sand Deposits.
				ft.	
Later	2,000 (?)	.. ..	Emergence of 2 ft.	0	Parallel dunes*
Recent	2,500 (?)	.. ..	Submergence of at least 7 ft.	+ 2	Deposition in river valleys, estuaries and along coastline
	..	.. ..	Emergence of at least 10 ft.	Down at least to −5	p5 dunes
Mid-recent	3,000 (?)	.. ..	Emergence of 5 ft.	+ 5	p10 dunes. Deposition along coastline
Earlier Recent	4,000 (?)	.. ..	Submergence of 40 ft.	+ 10	Deposition in rivers, valleys and estuaries
Late	23,000	Würm 3 ..	Emergence of 50 ft.	− 30	p20 dunes
Pleistocene	..	Würm 2/3 .. (Monasterian II)	Submergence of about 270 ft.	+ 20	Deposition in rivers, valleys and estuaries
	72,000	Würm 2 .. Würm 1/2	Emergence of about 295 ft.	−250	p45 dunes
	115,000	Würm 1			
	150,000	Riss-Würm Interglacial (Monasterian I)	Submergence of about 295 ft.	+ 45	Deposition in rivers, valleys, estuaries, and along coastline
	188,000 to 235,000	Riss Glacial ..	Emergence of 350 ft.	−250(?)	p100 dunes
Middle Pleistocene	250,000 to 425,000	Mindel-Riss interglacial (Tyrrhenian)	Submergence ..	+100	Deposition in rivers, valleys, estuaries, and along coastline

* The sea is now rising about 10 cm. per century (*see* footnote Table 14).

Distribution of Sand, Clarence River to Stradbroke Island.

The main masses of sand occur along the southern part of the Queensland coast, from Stradbroke Island to Frazer Island. Their relationship to river-mouths which are the immediate sources of the sediment indicate that the sands up to North Stradbroke Island, and probably most of Moreton Island, came from the Clarence Basin. The sand farther north, up to and including Frazer Island, came mainly from the Moreton area. It is intended here to discuss the distribution of sand along the stretch of coast that has been examined in detail, that is, from the Clarence River to North Stradbroke Island. In doing so, use will be made of the correlation with the Pleistocene and Recent fluctuations in sea level given in Table 15.

The carbonaceous sand on North Stradbroke Island, and the earliest transgressive dunes on all the large islands, suggest that these areas had been built up to or a little above sea level during the time of the mid-Pleistocene +100-foot sea level. The inter-glacial stage to which that sea level is attributed was of long duration, and it is likely that much of the coastline there became silted by sediment. In the ensuing glacial interval of low sea level most of this poorly consolidated and unconsolidated material was washed down the emerged coastal strip into the sea. It remained *in situ* in relatively small areas that were separated by low-lying corridors or sea-lanes from the consolidated mainland and so preserved from erosion by its drainage. In these areas the sandy sediments comprising high-level water-laid deposits and the later dunes were stabilized by a cover of vegetation, which protected them from wind-erosion. Little erosion was accomplished by creeks, because the rain-water soaked readily into the sand, and moved laterally by percolation. The 45-foot sea is represented by water-laid sands and dunes distributed in very much the same localities as those of the earlier 100-foot sea. High-level heathland and swamp-land between Evans Head and the Clarence River may belong to this period. On North Stradbroke Island, the p45 dunes climbed up the slopes of the old p100 dunes. The latter were by now firmly indurated by organic matter and iron oxide deposited between the grains, and they had become somewhat impervious. Rain-water tended to collect in creeks, which flowed south-south-easterly in the valleys between the long sand-ridges, and caused appreciable erosion of some of the p45 dunes.

The +20-foot sea did not last long enough to permit heavy sedimentation of the coastline, except perhaps for short distances north of the principal streams. Stretches of heathland between the Clarence River and Evans Head, near Broadwater north of Evans Head, and a very small area of elevated swampland just north of the Richmond River mouth, probably originated in this way, but they have not been examined in detail. The remaining stretch of mainland coast probably continued to present the appearance of drowning after the submergence of more than 250 feet that culminated in the +20-foot sea. On North Stradbroke Island, marine abrasion must have cut a platform at the +20-foot level, but this has been largely covered by later dunes, and was not recognized during the reconnaissance surveys of the island. The p20 dunes which followed or accompanied the recession of the sea from the +20-foot level are clearly outlined. Blue Lake, $\frac{1}{2}$ to $\frac{3}{4}$ mile inland from the Eighteen Mile Swamp, was first formed when the waters of several creeks flowing over the indurated p100 and p45 dunes were dammed back. Remnants of dunes of the same period probably occur also at several localities along the mainland coast, e.g. near Cudgen Head, just north of the Richmond River, and within a few miles north and south of Evans Head.

The +20-foot sea is thought to have been succeeded by an emergence of 50 feet, and then a submergence of 40 feet, resulting in the +10-foot sea. The +10-foot heathlands are not extensive, except near the mouths of the Clarence and Richmond Rivers, and they have not been found north of Norries Head. Their distribution apparently gives a picture of the extent of the sedimentation of the coast at that time, by northward drift of sand. On North Stradbroke Island, p10 dunes can be recognized, but they are not well developed, in part because of the minor amount of sedimentation during the interval of the +10-foot sea, and in part because of the small emergence that succeeded it.

The +5-foot heathlands have been observed at several localities from Lennox Head to North Labrador 3 miles north of Southport, and p5 transgressive dunes are well developed on North Stradbroke Island. The occurrence of the heathlands a considerable distance farther north than the earlier ones at +10-feet points to more general sedimentation along the coastline, which is what would be expected if the +5-foot sea directly succeeded the +10-foot sea. The p5 transgressive dunes are more extensive than are the p10 dunes; this is due firstly to the more advanced sedimentation of the +5-foot coastline, and secondly to the larger emergence which succeeded it.

The dune-belts adjacent to the present beaches, which might be termed the p2 dunes, have developed along the entire length of the coast, indicating the presence of a corresponding fringe of sediment in the littoral zone before the +2-foot sea receded. The formation of this fringe of sediment indicates that the earlier —5(?)-foot sea was of short duration, and little of the sediment along the coast and in the river valleys, deposited during the time of the +5-foot sea, had been washed down into it.

The preceding paragraphs have outlined the history of the development of the sand deposits along the coast. An important factor which has been omitted is the erosion of the deposits that begins soon after the emergence that elevates them above sea level. Any series of dunes, and emerged littoral and estuarine deposits, may be referred to a particular sea-level, that which prevailed before the emergence; and the erosion referred to here is the marine erosion that takes place at the stable sea level after the emergence. Thus, the p2 dunes, paradoxically, are not at all well represented for a considerable distance northwards from the mouths of the Clarence and Richmond Rivers, which were the sources of their sand. Much of this coast-line consists of low cliffs of indurated sand, cut into heathlands of the +10-foot level. Along other portions of it, swamps extend practically to the sea, and are separated from it only by a low foredune 20 feet or less in width, formed from sand blown up from the present-day beach, and advancing just ahead of the landward-advancing shore-line. It can be taken for granted that parallel dunes developed along this entire stretch of coast during the final 2-foot emergence, but they have since been removed by erosion. The quantity of sand brought down by the rivers is insufficient to replace what is being lost by northward migration. Conversely, the migrating sand is preventing much erosion of the coastal dunes farther north. The effects of the erosion are obvious as far north as Potts Point; and they are more obvious on long beaches that terminate at river mouths than on short ones enclosed between prominent headlands.

The sand deposits of the +5-foot sea have been recognized between Lennox Head and North Labrador. They may occur farther south towards the Clarence River, but are not conspicuous, and presumably have been removed, in part at least, by erosion during the interval of the +2-foot sea.

The sand between the Clarence River and North Stradbroke Island has resulted from the abundant quantities suddenly made available during several epochs of emergence, separate by intervals of stability after submergence, during which renewed supplies accumulated in river valleys and estuaries, and along the coast. Its distribution has resulted from northward transport along the coast, and from retention by headlands of consolidated rock, and by outlying areas of consolidated rock separated by low-lying corridors from erosion by the mainland drainage. The formation and distribution of the sand deposits are summarized in Table 16.

MINERAL DEPOSITS.

Occurrence.

Heavy-mineral deposits occur on present-day beaches, and on former beaches that occur beneath parallel dunes and in emerged heathlands. Deposits below present sea level are found at the seaward edge of some of the +5-foot heathlands. On North Stradbroke Island, heavy minerals from earlier beaches have been blown up into large low-grade deposits in some of the later transgressive dunes.

Heavy minerals are deposited by the surf on the upper part of a beach during stormy weather, and form a "seam" which may extend unbroken along the beach for the greater part of its length. It is pale grey to dark grey or black in colour, according to the relative amounts of zircon, rutile, and ilmenite, which form white, brownish-black, and black sands, respectively. The width of a seam commonly ranges from 30 to 50 feet. In cross-section, it appears wedge-shaped, tapering off gradually down the beach, and dipping bodily in the same direction at an angle of a few degrees. The thickest deposits occur on beaches that terminate northwards at a headland or other natural barrier. Such deposits may be five feet thick near the headland, and taper off gradually towards the south. In calm weather, the upper part of the beach seam is soon covered by white quartz sand blown up from the beach. The part within the tidal range, unless covered by the same white sand, is gradually washed down seawards.

TABLE 16.—SAND DEPOSITS BETWEEN CLARENCE RIVER AND NORTH STRADBROKE ISLAND, CORRULATED WITH EUSTATIC MOVEMENTS.

Eustatic Movement.	Level of Sea, Related to Present Sea-Level.	Sand Deposits.	Remarks.
Contemporaneous rise in sea level	0	Parallel dunes being converted to transgressive dunes notably on Stradbroke Island	The sea-level has been rising during the last century, and the present rate is about 10 cm. per century. Erosion of sand deposits is being accelerated. South and North Stradbroke Islands separated 50 years ago
Emergence of 2 feet	Slightly below present sea-level	Parallel dunes and other beach dunes (p2 dunes). Emerged sand-flats from portions of the low-lying coastal plain	Parallel dunes formed from emerged sand along centre coast. Sea erosion of dunes commences at southern end of coastal stretch, viz. near Clarence River mouth. North Stradbroke Island tied to mainland
Submergence of at least 7 feet ..	+ 2′	Deposition of estuarine flats &c. which now form portions of the low-lying coastal plain	Minor drowning of coast, but during period of +2-foot sea it became sedimented along entire length. Erosion of sand deposits laid down by the +5-foot sea
Emergence of at least 10 feet ..	− 5′ or lower	p5 dunes on North Stradbroke Island. Probably also remnants of dunes at Cudgen Head, Norries Head, Tallow Beach and Ballina	Erosion of sand deposits laid down by the +5-foot sea
Emergence of 5 feet	+ 5′	Deposition of littoral and estuarine sands which now form the +5-foot heathlands between Lennox Head and North Labrador	During the interval of the +5-foot sea, sand migrated as far as North Labrador
	Falling sea-level	p10 dunes on North Stradbroke Island	Dunes small because of lack of sediment and small magnitude of emergence
Submergence of 40 feet ..	+ 10′	Deposition of litterol and estuarine sands which now form the +10-foot heathlands north and south of Evans Head, and at Norries Head	Sand brought down by Clarence and Richmond River had migrated northward apparently as far as Norries Head
Emergence of 50 feet	− 30′	p20 dunes on North Stradbroke Island. Probably dune remnants at Ballina, near Broadwater, and south of Evans Head	Comparatively large dunes on Stradbroke Island built from emerged sea-floor sand derived from erosion of earlier dunes, probably no appreciable dunes on mainland, except near river mouths
Submergence of about 270 feet ..	+ 20′	Deposition of littoral and estuarine sands which now appear as heathlands near Broadwater, and (?) south of Evans Head	Deeply-drowned coast; sedimented up to sea-level only near mouths of rivers. Erosion of transgressive dunes on North Stradbroke Island and deposition on sea floor to form sloping sandy shelf at shallow depth
Emergence of about 295 feet ..	− 250′	p45 dunes on North Stradbroke Island	Probably massive parallel dunes were built all along the coast, and later converted to transgressive dunes. They persist only where separated from the mainland drainage by a low-lying corridor
Submergence of about 295 feet ..	+ 45′	Organically-bonded sand at about 30 to 60 feet on North Stradbroke Island	During long periods of stable sea level, sea became shallowed by sediment for considerable distance from shore. Erosion of p100 dunes on North Stradbroke Island, &c. forms shallow sandy shelf
Emergence of 350 feet ..	− 250′	p100 dunes, rising to 800 feet on North Stradbroke Island	Probably massive parallel dunes were built all along the coast, and later converted to transgressive dunes. They persist only where separated from the mainland drainage by a low-lying corridor
Submergence	+ 100′	Carbonaceous sand at about 90 to 110 feet on North Stradbroke Island	During long periods of stable sea-level, sea became shallowed by sediment for considerable distance from shore. Sand bars and spits at islands, e.g. near Dunwich and Point Lookout

The richest and largest beach seams occur between Southport and Tallow Beach, south of Cape Byron. Their constituent minerals, in order of abundance, are zircon, rutile, ilmenite, and minor quantities of several others, including monazite. Seams similar in composition, but smaller in their dimensions, occur between Southport and Point Lookout on North Stradbroke Island, between Tallow Beach and the mouth of the Clarence River, on beaches between the Macleay and Manning Rivers, and between Swansea and Tuggerah Lake. Connah (1948) recorded beach seams during a reconnaissance survey from Stradbroke Island to the north end of Frazer Island. Their most abundant mineral is ilmenite.

The deposits beneath the parallel dunes consist of two or more parallel seams similar in shape and attitude to the beach seams. Where several parallel seams are present, they appear in cross-section to be louvred or arranged *en echelon*. All dip towards the beach, and the upper part of a later seam overlaps the lower part of the preceding seam, from which it is usually separated by a layer of white sand.

The deposits beneath parallel dunes are best developed near Cudgen Beach, on North Stradbroke Island, from Broadbeach to North Burleigh, near Tallow Beach, and near Norries Head. These areas have contained the largest reserves of heavy minerals. Similar deposits may occur between Perpendicular Point and Diamond Head, north of the Manning River. Their extent is not known, but they are probably much smaller than those farther north. Irrespective of whether parallel dunes appear within an area, deposits generally occur beneath the foredune. From Hastings Point to two miles or so past Brunswick Heads, and along the northern part of Seven Mile Beach, they contain a large proportion of the reserves.

The heathland areas represent littoral zones, estuarine flats, and coastal dunes, similar to those of the present-day coast, although variously modified by erosion and redistribution of sand. The surface elevations commonly range from 5 to 20 feet above the former high-water level, that is from 10 to 25 feet above present high water. A heathland deposit generally occurs beneath a low arcuate sand ridge, or adjacent to it on the seaward side. It represents a foredune that formed at the same time as the heavy minerals were deposited. The sand that covers the deposits is loose from the surface to a depth of several feet, below which the sand and the deposits are usually cemented and indurated by organic matter and perhaps iron oxide, deposited between their grains.

A well-preserved heathland deposit of the +10-foot sea occurs at Macaulay's Lead, north of the Clarence River, and a remnant of one has been intersected in a bore near Norries Head. Deposits near Broadwater, north of Evans Head, are probably of the same type. Deposits in the +5-foot heathlands are known at North Burleigh and near Seven Mile Beach.

Low-level deposits of the —5(?)-foot sea have been found adjacent to the +5-foot heathland on its seaward ledge at North Burleigh and at Tugun. Others probably occur at Norries Head, Tallow Beach, and North Stradbroke

Island. The —5(?)-foot deposits have been intersected by bores, but being well below ground-water level, they have not been observed in any excavations. In their lower parts, they are indurated and hard, and, in places, contain beds of pebbles and boulders. They could not be completely penetrated by the hand-boring equipment that was used, and although it is thought that the bores went close to the bottoms of the deposits, this is not certain.

Dune concentrations possibly of economic grade occur, as far as is known, only on North Stradbroke Island within transgressive dunes of the last three stages—the p20, p10, and p5 dunes—from 3 miles to 13 miles south of Point Lookout. These dunes generally contain about 2.5 ± 0.5 per cent. by volume of heavy minerals, and in places up to about 4 per cent. The p45 dunes commonly have 1 per cent. ± 0.5 per cent., and in places 2 per cent. or a little better. In the p100 dunes, many bores yield only traces of heavy minerals, and most of them yield less than 0.5 per cent. Samples obtained from scout bores put down by Zinc Corporation (Donaldson & Stuart, 1948) on Moreton and Curtiss Islands yielded, with few exceptions, less than 1 per cent. heavy mineral. No information is available on any possible deposits in the dunes of Frazer Island. A few samples examined by the Bureau of Mineral Resources contained very little heavy mineral.

Origin of Deposits.

Beach Seams.

In stormy weather the turbulence of the ocean water from the shoreline to the zone of the breakers brings into suspension large quantities of sand, which is gradually worked shoreward and carried up the beach by the surf. The ebb-flow from the surf and the general return of water from the breaking storm-waves gathers into channels about 50 feet wide, which flow seaward at a considerable speed. The longshore currents caused by the south-easterly gales deflect them to the north at an acute angle to the beach. These currents are well known to surfers, and they have been described by Shephard *et al.* (1941) under the name of "rip currents". Fine sediment is carried outwards by them, and probably large volumes of sand are worked seaward and northward in the shifting channels which they cut in the sandy bottom. In storm periods the ebb-flow and rip currents assisted by gravitation on the sloping beach have more than sufficient energy to return the quartz sand that was carried up by the surf. Hence, excess sand is returned seaward and the beach slope reduced until the quantity of sand being returned is equal to that being carried up the beach. The energy of the returning water is not sufficient to carry back the heavy minerals, and they are deposited near the top of the beach. During calm weather, the movement of quartz-sand is reversed. The turbulence within the breaker-zone is sufficient to bring quartz-sand into suspension and it is carried on to the beach. Some is blown by the wind to the upper part of the beach, steepening its gradient, and at the same time covering the heavy-mineral seam.

The development of parallel seams covered by parallel dunes may be expected where the littoral zone is being shallowed by sedimentation or by emergence. In fine weather the wind-blown sand gradually builds out a platform or "berm" from the foot of the foredune. Its surface is commonly 6 to 8 feet above high-water level, and in a long period of favorable weather it may become half a chain wide. Assuming excess quantities of sand in the littoral zone, the beach may not be eroded back to the foredune. A seam of heavy minerals may be deposited somewhat seaward of the preceding seam, and a new foredune starts to build at the seaward edge of the berm. Repetition of this process at Cudgen Beach has resulted in the formation of at least 15 parallel dunes and a greater number of parallel seams beneath them.

The seams of heavy minerals in the heathlands originated in the same way as those on present-day beaches. In some of them, the heavy minerals differ in being much finer-grained. They were apparently deposited in deeply embayed parts of the coast, where shallowing by sedimentation or emergence forced the waves to break far from the shore, and so dissipate much of their energy before they reached the beach. In this environment only fine-grained heavy minerals could be transported, and the larger quartz grains tended to be deposited with them, resulting in less highly concentrated seams than on more open beaches.

Deposits in Transgressive Dunes.

The formation of deposits in transgressive dunes must depend upon earlier concentration of the heavy minerals in beach seams. Presumably these were covered by parallel dunes, which were later dissected by blowouts, and carried up by the wind, together with the underlying seams, into transgressive dunes. Stradbroke Island, which contains the only known deposits of this type, is distinguished from the other islands in that much of its sand was derived from the Clarence Basin. There, as has already been noted (Beazley, 1950), the stream sands and sandstones contain far greater proportions of heavy minerals than the other areas examined, and they have yielded heavy-mineral deposits along the coast from the Clarence River to the north end of Stradbroke Island. Point Lookout has been an effective barrier to further migration of heavy minerals, and the deposits on Moreton Island are relatively small even though it received large volumes of quartz sand. On Stradbroke Island, the heavy-mineral content increases progressively from the older to the younger dunes. The work done by Zinc Corporation indicates that the deposits occur almost entirely within the younger dunes that flank the massive and steeply-rising areas of older dunes. This high part of the island is traversed by creeks, flowing south-south-east, which have been continually carrying sand and minor amounts of heavy minerals to the ocean beach. As a result, some of the quartz sand has been constantly removed by drifting beyond the island, and heavy minerals have been concentrated along the beach.

During periods of submergence the elimination of quartz sand and concentration of heavy minerals was accelerated through sea-erosion of dunes.

MINERALOGICAL COMPOSITION.

The beach sand deposits consist of heavy minerals mixed with quartz sand in proportions ranging from a few per cent. to more than 90 per cent. by weight. Table 17, which is based on Table III. of Gardner (1951), give the compositions of the heavy minerals along the coast after separation from the quartz sand. The accuracy of the figures given for an area depends in general on the amount of sampling that was done. Those for the localities between the Clarence River and Southport, and for the beach south of Grants Head, and those near Swansea, are based mainly on the results of detailed boring by the Bureau of Mineral Resources, and on production records. The figures for Stradbroke Island, and for the deposits from Moreton Island to Frazer Island, are based on the results of less-detailed sampling during investigations by the Queensland Geological Survey (Connah, 1948; Morton, 1948) and by Zinc Corporation (Donaldson and Stuart, 1948). The compositions given for other localities are those of random samples which may not be accurately representative of deposits.

The estimates of composition given in the past by different investigators for concentrates from the same area may differ for three reasons. First, the zircon-content of a seam is highest where the natural concentration has been most effective. This is probably the reason why some of the compositions of Beazley (1950), given in Table 17, show more zircon than those estimated by the Bureau of Mineral Resources. Secondly, some rutile grains cannot be distinguished under the microscope from ilmenite grains, which they closely resemble in colour and lustre. Reliable estimates of the two minerals can be made only after magnetic separation of the ilmenite. Through failure to do this many analyses made by grain-counting in earlier years have over-estimated ilmenite and under-estimated rutile. Thirdly, the deposits on the ocean beaches are generally higher in zircon than those beneath the adjacent dunes, and depletion of the beach deposits by mining results in a reduction in the average zircon content of the area. The compositions of sub-dune and inland deposits are discussed in the section on the distribution of the heavy minerals (p. 52ff.).

TABLE 17.—AVERAGE COMPOSITIONS OF HEAVY-MINERAL CONCENTRATES IN BEACH DEPOSITS.

Locality.	Zircon.	Rutile.	Ilmenite.	Monazite.
	%	%	%	%
Narooma (1 sample)	12	7	80	0.16
Shoalhaven River mouth, 1 mile north of (1 sample)	22	18	59	0.8
Shellharbour (2 samples)	26	45	28	0.3
	45	38	17	0.7
Port Kembla (average of 10 samples)	38	29	17	0.2
	(contains also 16% magnetite).			
Composition range of 8 samples	31–45	20–30	15–22	0–0.3
		(magnetite 13–17)		
Bellambi Beach	38	37	24	0.7
Terrigal (average of 7 samples)	38	38	21	2.5

TABLE 17.—AVERAGE COMPOSITIONS OF HEAVY-MINERAL CONCENTRATES IN BEACH DEPOSITS—*continued.*

Locality.	Zircon.	Rutile.	Ilmenite.	Monazite.
	%	%	%	%
Swansea area—				
Caves Beach..	33	44	22	2
Catherine Hill Bay	50	42	6	1
Laurieton area (Fisher, 1953), Grants Head to 1,400ft. south	40	39	20	1.4
Woolgoolga	34	41	24	1.0
Wooli, 8 miles north of (average of 3 samples) ..	63	27	10	0.3
Yamba, average of 4 reported compositions ..	65	24	11	N.D.
Main surf beach (1 sample)	58	29	13	0.3
Woody Head, 2 to 5 miles north of	48	31	21	0.8
Evans Head, 1 to 2 miles north of	44	30	25	1.0
Ballina; beach top, just south of Richmond River (Beazley, 1950)	55	24	21	0.7
Seven Mile Beach (Schnapper Rocks to Lennox Head)	53	28	18	0.8
Tallow Beach (Cape Byron to mouth of Tallow Creek)	53	28	18	0.6
Brunswick Heads to Cape Byron	54	27	18	0.7
Potts Point to Brunswick Heads—				
New Brighton Beach	47	34	19	0.5
Crabbes Creek Beach	39	39	22	0.5
Mooball Beach	41	37	21	0.5
Cudgera Beach (Hastings Point to Potts Point) ..	48	32	19	0.7
Norries Head to Hastings Point	51	29	19	0.8
Cudgen Beach (Cudgen Head to Norries Head) ..	51	28	21	0.5
Beach top, 3 miles south of Cudgen Head* ..	56	22	22	0.6
Fingal Point to Cudgen Head	46	32	21	0.7
Tweed Heads to Fingal Point	49	29	22	0.6
Tugun Beach	42	32	25	0.5
Beach top, 4 chains north of surf pavilion* ..	49	27	23	0.8
Flat Rock Creek (Currumbin)	40	37	23	0.5
Palm Beach	41	36	23	0.5
Burleigh, beach and foredune, from South Nobby to 1,700 ft. south	47	31	21	1.1
North Burleigh (Broadbeach to South Nobby) ..	41	36	23	0.7
Broadbeach§	38	36	25	0.5
Southport, the Spit	38	37	24	0.6
Two miles south of Nerang River mouth* ..	43	29	28	0.8
South Stradbroke Island†	34	35	30	0.5
Average of 4 samples*	34	34	32	0.4
North Stradbroke Island†	31	37	31	0.2
Average of 4 samples*	32	35	33	0.4
Moreton Island	23	18	58	0.9
Bribie Island (average of 4 samples)	22	18	58	1.1
Three miles south of north end*	23	20	57	0.5
Caloundra†	21	18	59	2.0
Maroochydore (average of 2 samples)	35	16	49	0.3
Noosa†	20	17	63	0.9
Frazer Island†	25	17	57	0.6
Burnett Heads‡	3	2	94	?
Bustard Head (1 sample)	34	4	61	N.D.
Facing Island‡..	7	9	80	?
Mackay (Blacks Beach) (1 sample)	9	2	88	0.4
	(the ilmenite contains a "high proportion" of magnetite)			
Cannon Vale Beach (average of 2 samples) ..	trace	..	62	?
	(also magnetite 28 and hypersthene 10)			
Johnstone River about 50 miles south of Cairns‡ ..	1.4	1.8	84	1.2
	(also tantalite 0.9)			
Thursday Island, near Cape York (average of 3 samples)	4	0.1	95	?

* Beazley, 1950. † Connah, 1948; Morton, 1948. N.D.—Not determined. ‡ Donaldson and Stuart, 1948.
§ May be modified because of mining, *see* Table 21.

Between the Clarence River and North Stradbroke Island, the heavy minerals consist essentially of zircon, rutile, ilmenite, and a very small proportion of monazite. Others occurring in smaller amounts are described below, and listed in Table 19. Zircon is by far the most abundant mineral in the concentrates in at least the southern half of this stretch of coast.

On North Stradbroke Island, ilmenite is the dominant mineral except in the deposits on the present ocean beach, where it ranks equally in amount with both zircon and rutile. Typical compositions are given in Table 18.

TABLE 18.—TREND OF CHANGE IN COMPOSITION OF HEAVY CONCENTRATES FROM BEACHES BETWEEN THE CLARENCE RIVER AND NORTH STRADBROKE ISLAND.

Locality.	Heavy Minerals, in Weight Per Cent.			
	Zircon.	Rutile.	Ilmenite.	Monazite.
Between Clarence River and Cudgen Beach	52 ± 1	28	19 ± 1	0.6 ± 0.1
Cudgen Head to North Burleigh	44 ± 3	34 ± 2	23 ± 2	0.8 ± 0.3
Broadbeach to North Stradbroke Island Beach	35 ± 3	36 ± 1	28 ± 3	0.6 ± 0.2

Other minerals which occur in small amounts have been disregarded in statements of composition. With the exceptions of minor amounts of tin and garnet, they have no commercial value, and most of them are sufficiently low in specific gravity to be largely eliminated in the tailings when the sands are being tabled or otherwise concentrated. These rarer minerals in the Cudgen area were obtained by careful panning of a large middling cut taken during tabling. They are shown in Table 19.

TABLE 19.—RARER HEAVY MINERALS IN BEACH SANDS IN THE CUDGEN AREA.

Mineral.	Weight Per Cent.	Mineral.	Weight Per Cent.
Tourmaline	1.6	Staurolite	Less than 0.05
Garnet	1.3	Andalusite	Less than 0.05
Chromite	0.6	Brown Spinel	Less than 0.02
Leucoxene	0.4	Corundum	Less than 0.02
Cassiterite	0.1	Hypersthene	Less than 0.01
Epidote	Less than 0.1	Pleonaste	Less than 0.01
Green Spinel	Less than 0.1		

The beach-sand deposits are relatively high in grade, containing at least 10 per cent. by weight of heavy minerals. Those in the transgressive dunes are lower in grade, averaging about 2 per cent. by volume or a little more than 3 per cent. by weight. The average composition of the heavy-mineral concentrate in both these types of deposits after separating them from the admixed quartz sand is given in Table 20.

TABLE 20.—OVERALL AVERAGE COMPOSITION OF HEAVY MINERALS IN DEPOSITS BETWEEN THE CLARENCE RIVER AND NORTH STRADBROKE ISLAND (IN WEIGHT PER CENT.).

Locality.	Zircon.	Rutile.	Ilmenite.	Monazite.
Clarence River to North Stradbroke Island, excluding minerals in transgressive dunes	40.6	31.6	27.3	0.5
Deposits in transgressive dunes on North Stradbroke Island (from Donaldson and Stuart, 1948) ..	28	27	44	0.3

The compositions of the deposits along other parts of the coast are not known in such detail. Minor concentrations in the south coast of New South Wales near Bulli and Shellharbour, and deposits near Swansea and at Grants Head on the north coast, are similar in composition to those already discussed. The predominant minerals are zircon and rutile. This applies also to deposits worked in former years near Woolgoolga, Wooli, and Yamba. Ilmenite is the dominant constituent north of Stradbroke Island, and probably in the minor concentrations on the south coast of New South Wales south of Shellharbour. The average compositions from Moreton Island to Frazer Island are—

Zircon.	Rutile.	Ilmenite.	Monazite.
%	%	%	%
20 ± 2	18 ± 1	60 ± 3	0.9 to 2.0

North of Frazer Island, the ilmenite continues to increase, and is accompanied by an appreciable proportion of magnetite. Monazite continues to appear in the concentrates, in greater amount than in the deposits south of Moreton Island. Monazite occurs in more than average proportions in the deposits between Swansea and Woolgoolga.

The beach sand minerals have been described by Whitworth (1931) and Beazley (1950). Only brief general notes on the principal ones are given here. The grains are nearly all rounded, the degree of rounding increasing progressively from ilmenite, to rutile, to zircon, to monazite. In average size, the zircon and rutile are approximately equal, their median diameters ranging from 0.112 mm. to 0.114 mm. Ilmenite is slightly larger, its median diameter ranging from 0.116 to 0.118 mm., and monazite is notably smaller, having an average diameter of about 0.086 mm.

The zircon grains are generally clear and colourless and readily recognized because of their high refractive index. Rutile grains range in colour through reddish-brown to black, and in lustre from vitreous almost to metallic. The ilmenite is greyish-black in reflected light and its lustre approaches metallic. Occasional grains are pitted or show partial alteration to leucoxene. The monazite grains are small and well rounded. Many of them are pear-shaped; others are curved inwards along one side, suggesting a bean shape. Their colour is pale honey-yellow and their lustre resinous, although somewhat masked by a finely pitted or "frosted" surface.

Some zircon grains contain dark inclusions. They are feebly magnetic and are removed during magnetic cleaning of the zircon concentrate. A small proportion of the rutile grains are slightly ferriferous and presumably these are also eliminated during magnetic cleaning of the rutile product. Stillwell (1949) attributed the dark colour of non-magnetic rutile grains, described as black, to a strong trace of chromium which was revealed in a spectroscopic examination of the sample. After separation the zircon ($ZrSiO_4$) and the rutile (TiO_2) are virtually free from impurities and are marketed as high-grade products. The ilmenite ($FeTiO_3$) contains a small proportion of chromite which occurs as discrete particles within it (Stillwell, 1949; Stillwell and Baker, 1948). This renders it unsuitable, at present, for paint manufacture, and little of it has yet been marketed. However, a fraction relatively low in chromite can be separated from it. This will possibly enable utilization of some at least of the ilmenite on and north of Stradbroke Island, which is initially lower in chromite than that in the deposits farther south. Partial assays of samples of ilmenite concentrates are given in Table 21.

TABLE 21.—PARTIAL ANALYSIS OF SOME EAST COAST ILMENITE CONCENTRATES.

Locality.	TiO_2 (Per cent.).	Iron Oxide as FeO. (Per cent.).	Cr_2O_3 (Per cent.).
Norries Head*	45.80	35.98	4.83
Tugun†	?	?	5.0
North Burleigh†	?	?	5.2
North Stradbroke Island, beach and dune sands*	50.50	41.69	1.37
Moreton Island†	49.68	?	1.35
Maroochydore†	?	?	0.6
Noosa Heads†	50.9	?	0.35
Inskip Point†	52.6	?	0.9
Bundaberg‡	51.55	?	Less than 0.01
Facing Island‡	42.17	?	0.12
Curtis Island‡	52.55	?	0.08
Thursday Island*	56.2	?	0.30

* C.S.I.R.O., 1948. † Queensland Mines Department. ‡ Donaldson and Stuart, 1948.

Fractions of differing chromite-content have been separated magnetically from the concentrates given in Table 21 for Norries Head and Stradbroke Island. Their Cr_2O_3 contents are given in the following table (C.S.I.R.O., 1948):—

Product.	Weight Per Cent. of Original Concentrate.		Cr_2O_3. (Per cent.).	
	Norries Head.	Stradbroke Island.	Norries Head.	Stradbroke Island.
Concentrate 1 (most highly magnetic)	5.7	8.5	1.75	0.45
Concentrate 2	13.3	7.1	0.65	0.3
Concentrate 3	28.9	47.9	0.55	0.2
Concentrate 4	46.9	26.4	8.65	1.7
Tailings (least magnetic)	5.4	10.1	10.9	6.0

It can be seen that nearly half the Stradbroke Island ilmenite can be separated out as a concentrate containing no more than 0.2 per cent. Cr_2O_3. Many of the concentrates from farther north are almost free of chromite, but the deposits, at least from Bundaberg to Curtis Island, are too small to be worth working.

The monazite, a phosphate of cerium and other rare earths, including thorium, has been produced as a by-product and marketed mainly for its cerium. An analysis of monazite from Byron Bay (Wylie, 1950) is:

La_2O_3.	Ce_2O_3.	Pr_2O_3.	Nd_2O_3.	Sm_2O_3.	ThO_2.
% 15.5	% 27.2	% 3.37	% 11.9	% 2.24	% 7.35

Estimates of the thoria content at several localities are:

Woolgoolga	6.3 per cent. ThO_2
Byron Bay	7.2 " " "
Cudgen	7 4 " " "
North Burleigh	7.3 " " "

The samples obtained at each individual area by the Bureau of Mineral Resources during the beach sands investigation were compared radiometrically with a standard sample from Byron Bay, stated to contain 6.6 per cent. ThO_2. The thoria content in the area investigated, i.e., from Southport to the Clarence River mouth, was found to be virtually constant, at 6.6 ± 0.3 per cent.

SIZE COMPOSITION.

Beazley (1950) found, as a result of numerous mechanical analyses, that the beach-sand heavy minerals between the Richmond River and North Stradbroke Island are well-sorted, and have median diameters ranging from 0.110 mm. to 0.133 mm. The average grain-size increases noticeably near the southern ends of the beaches on North and South Stradbroke Islands. This has been thought to be due to the deposition of heavy minerals at these localities, but, since the beaches have no southern headlands to protect them from erosion, the increase in grain-size may be due to selective removal of smaller grains. The grain-size increased markedly near some of the northern headlands on the Queensland coast, between Moreton and Frazer Islands. Beazley suggests that the large grains are derived from the adjacent headlands of Mesozoic sandstone. An alternative explanation that may apply in some cases is that strong rip currents are prevalent near these northern headlands, and they remove the smaller grains. The same explanation is advanced later to account for a higher proportion of zircon in the concentrates near the northern ends of beaches that terminate at headlands.

A sample obtained near South Nobby, $\frac{1}{4}$ mile inland, had a larger grain-size than any of the beach sands, and its sorting was much poorer. It was taken from a bore, from the surface to a depth of 6 feet, and is evidently composed largely of coarse littoral sediment of the +5-foot heathland. This is noted in the description of that locality.

The heavy minerals on the transgressive dunes of North Stradbroke Island are very well sorted, and are a little smaller than the minerals in most of the beach-sand samples, having a median diameter of 0.110 mm.

Table 22 summarizes some of the results of mechanical analyses of the heavy minerals separated from typical samples.

TABLE 22.—FIRST AND THIRD QUARTILES AND MEDIAN DIAMETERS OF HEAVY MINERALS IN BEACH AND DUNE SANDS.

Adapted from Beazley (1950), Table II.

Locality.	First Quartile.	Median.	Third Quartile.
Richmond River mouth to North Burleigh ; beach seams (8 samples)	0.120 ± .002	0.113 ± .001	0.107 ± .001
South Nobby, most landward dune, ¼ mile inland ; composite sample from borehole 6 feet deep ..	0.190	0.149	0.112
Broadbeach, ¼ mile inland ; hollow between two dune ridges	0.120	0.111	0.103
South Stradbroke Island, 5 miles north of southern end ; top of beach	0.120	0.110	0.100
North Stradbroke Island ; transgressive dunes, from 1½ miles north to ½ mile south of Blue Lake and up to 1½ miles from ocean beach (4 samples) ..	0.120 to 0.121	0.110	0.100
South Stradbroke Island, ½ mile north of southern end ; seam exposed in sand cliff at top of beach	0.192	0.124	0.111
Point Arkwright, ¼ mile south of; in front of foredune	0.217	0.180	0.151

The heavy minerals obtained at the top of the beach on South Stradbroke Island (locality 4) were panned from quartz sand, which consists of the finer-grained fraction of the ordinary beach sand which has been carried by the wind to the top of the beach; its heavy minerals have the same size characteristics as those in the transgressive dunes of North Stradbroke Island. The sample from Broadbeach, ¼ mile inland, is similarly fine-grained, and was probably wind-deposited. Summarizing, the samples of locality 1 have size-grades typical of the heavy minerals in beach seams, that of locality 2 represents coarse littoral sediments of some of the emerged heathlands, samples from localities 3, 4 and 5 are typical of wind-deposited sands, and samples from localities 6 and 7 represent beach sands from which the smaller grains have been removed by selective erosion or transportation. In sample 7, some of the coarser grains may have been derived from nearby headlands of Mesozoic sandstone.

Sources of Minerals.

The average compositions of the principal heavy-mineral deposits and the proportions of the same minerals in rocks and stream sands in the source-areas are given in Table 23. The composition shown for Clarence sandstones was derived from Table 4 by omitting leucoxene. Only traces of this mineral are found in beach sands; presumably, because of its relatively low specific gravity, it is carried seawards beyond the beaches. The analyses of the stream sands have come from Table 6, and only those of the Orora River, which is outside the area of Tertiary basalts, have been included. The reason is that virtually all the excess ilmenite in the other stream sands, derived from Tertiary basalts, has a grain size smaller than 0.104 mm. (Table 7) ; yet in even the finer-grained deposits of the beach and dune sands, that is, those on the transgressive dunes, half of the heavy minerals exceed 0.110 mm. in diameter, and only a quarter of them are smaller than 0.1 mm. despite the distance they must have travelled. Thus the Tertiary basalts cannot be considered to be significant contributors to the heavy-mineral deposits. The composition given for the Moreton Area is that of the heavy minerals in the Brisbane River sands at Moggill. Ilmenite forms a large proportion of the concentrate, and, unlike that from the Tertiary basaltic rocks, it is relatively coarse-grained and may be expected to be deposited on beaches together with the zircon and rutile.

TABLE 23.—ZIRCON, RUTILE, ILMENITE, AND MONAZITE IN COASTAL SAND DEPOSITS AND IN SOURCE AREAS.

Locality.	Zircon.	Rutile.	Ilmenite.	Monazite.
Source Area, Clarence Basin : sandstones ..	41.4	33.1	20.4	5.1
Coastal Sand Deposits, Clarence River to North Stradbroke Island, excluding deposits in transgressive dunes ..	40.6	31.6	27.3	0.5
Source Area, Moreton area : Brisbane River Sands	24.4	20.7	51.5	3.4
Coastal Sand Deposits, North Stradbroke Island, transgressive dune deposits ..	28	27	44	0.3
Moreton Island to Frazer Island, beach deposits	18 to 25	17 to 19	57 to 63	0.6 to 2.0

If the Clarence area is considered to be the source of the heavy minerals between the Clarence River mouth and North Stradbroke Island, excluding the deposits in the transgressive dunes, it is necessary to account for the different proportions of monazite and ilmenite. The decrease in monazite is readily explained by abrasion: it is relatively soft, and in the coastal deposits has been reduced to a much smaller average size than the other minerals. The excess ilmenite may have been transported in part from the New England area and in part from Tertiary basaltic rocks. The quantities so derived must have been small, and probably most of the ilmenite was carried down in creeks to the +2-foot shoreline from the transgressive dunes.

The deposits from Moreton Island to Frazer Island are similar in composition to the heavy minerals in the Brisbane River Sands at Moggill, and even though this sampling is inadequate, it seems reasonable to suppose that they were derived from the Moreton area. Those in the transgressive dunes of North Stradbroke Island could be made up of heavy minerals from both the Clarence Basin and the Moreton area, supplemented by some of the coarser-grained of the ilmenite from the Tertiary basaltic rocks. At the time of the +100-foot and +45-foot seas, sandy sediment apparently extended well out at a shallow depth from the present shoreline. It may have come in part from the Brisbane, Albert, and Logan Rivers, and in part it may have been transported northwards from the Clarence and Richmond Rivers. The finer grain-size of the heavy minerals permits the inclusion of some of the ilmenite from the Tertiary basaltic rocks, and this may have been deposited, initially, at some depth below the surface of the +100-foot and +45-foot seas.

Distribution of Minerals.

General.

The general distribution of minerals along the coast has been indicated in the section dealing with the mineralogical composition of the deposits. Zircon and rutile are the dominant minerals between Shellharbour and South Stradbroke Island. North and south of this section of the coast ilmenite is the most abundant mineral, except in the beach deposits of North Stradbroke Island, where the three minerals occur in almost equal proportions. From Moreton Island to Frazer Island, ilmenite forms about 60 per cent. of the heavy minerals, and zircon and rutile about 20 per cent. each. North of Frazer Island, ilmenite, and up to 30 per cent. magnetite, constitute about 90 per cent. of the concentrates.

The largest quantities of heavy minerals are in the low-grade deposits in the transgressive dunes of North Stradbroke Island. Excluding these, by far the largest reserves occur between the Clarence River and North Stradbroke Island. This area has been carefully tested, and the distribution of minerals in it is known in some detail. The heavy minerals have been derived from those in the Clarence sandstones.

They became available not as a continuous supply but as separate large accessions during periods of emergence, and the present-day deposits were formed through the distribution of these specific increments.

Distribution in Seams.

The vertical distribution of the heavy minerals within seams in the Cudgen Beach area is illustrated in Table 24.

TABLE 24.—CUDGEN AREA: VARIATION IN A VERTICAL DIRECTION OF COMPOSITION OF HEAVY CONCENTRATES.

Co-ordinates of Bore from which Samples Taken, and Depth of Sample.	Percentage Composition of Concentrate (neglecting Garnet and other Minor Minerals).				Grade of Sample (lb. Heavy Mineral per Cubic Yard).
	Zircon.	Rutile.	Ilmenite	Monazite.	
15,000N/120W—					
5′ 0″– 9′ 6″	39.9	38.4	21.1	0.53	126
9′ 6″–10′ 0″	49.9	30.3	19.1	0.63	2,506
10′ 0″–13′ 0″	49.9	30.1	19.1	0.64	263
13′ 0″–13′ 9″	59.0	22.1	18.0	0.91	3,040
15′ 0″–17′ 0″	47.6	31.7	20.1	0.62	428
10,000N/120W—					
6′ 0″– 9′ 0″	39.6	37.6	22.1	0.67	173
10′ 9″–13′ 0″	45.7	32.3	21.2	0.78	1,310
13′ 0″–15′ 0″	40.2	37.9	21.4	0.50	870
15′ 0″–16′ 6″	56.4	23.5	19.0	1.13	1,590

The grades of the samples show that each bore intersected two overlapping seams, viz. in line 15,000N from 5 feet to 10 feet and from 10 feet down at least to 13 feet 9 inches, and in line 10,000N from 6 feet to 13 feet and from 13 feet to 16 feet 6 inches. It can be seen that a greater degree of concentration, indicated by an increase in the grade of the sample, is accompanied by an increase in the proportions of zircon and monazite, which are the heaviest minerals.

This applies in most seams, and it represents a partial separation of the constituents by simple gravitation. The decrease in grade towards the top of the deposit means an incr ase in the proportion of quartz sand. The concentrates from a shallow depth, which have the lowest proportions of zircon, are probably wind-blown, having been picked up from beach seams and carried up into the developing foredune. The relative constancy of the proportion of ilmenite is noteworthy.

Distribution in a Landward Direction.

Deposits that occur in the Cudgen area beneath parallel dunes, from the foredune to more than 1,500 feet inland, are shown in plan in Plate 15 on a scale of 1,000 feet to the inch. They are shown diagrammatically in Fig. 1 and their compositions are given in Table 25.

TABLE 25.—CUDGEN AREA: VARIATION IN COMPOSITION OF CONCENTRATES ACROSS THE DEPOSITS.

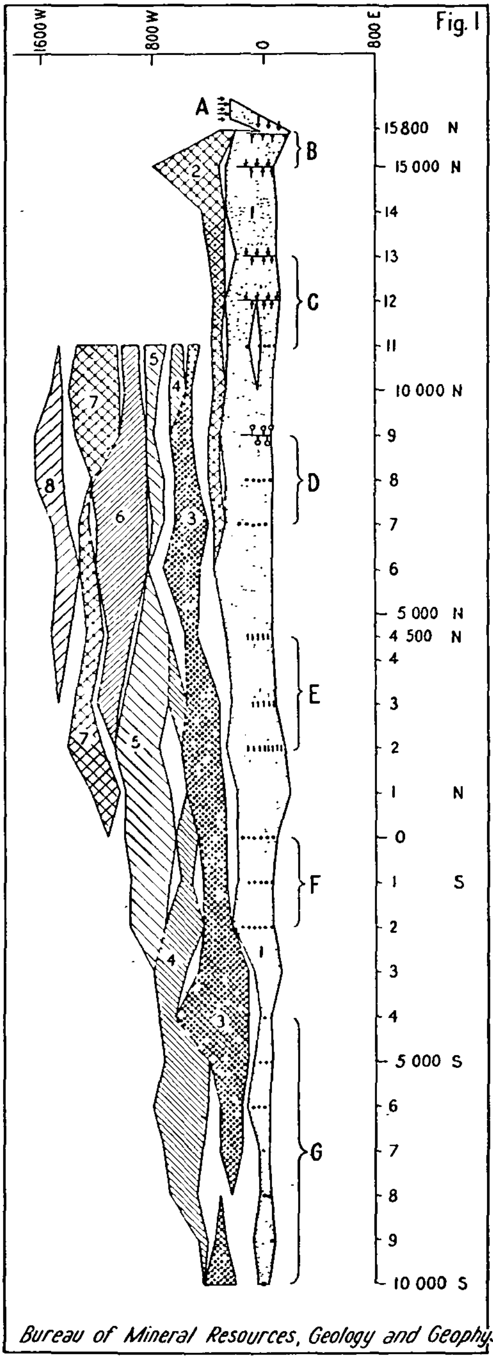
Deposit Shown in Fig. 1.	Average Percentage Composition (Neglecting Garnet and Other Minor Minerals).			
	Zircon.	Rutile	Ilmenite.	Monazite.
1	44.3	34.9	20.3	0.54
2	43.3	35.4	20.8	0.54
3	37.9	38.6	22.9	0.53
4	38.7	38.7	22.1	0.55
5	39.5	37.2	22.8	0.53
6	36.2	39.9	23.4	0.50
7	36.9	40.0	22.6	0.53
8	44.2	35.1	20.2	0.54

It can be seen that the proportion of zircon is high and rutile is correspondingly low in deposits 1 and 2 on and adjacent to the present beach, and in the most landward deposit, No. 8. No. 8 deposit occurs beneath the seaward slope of an earlier foredune, which actually is the highest dune in the area. Apparently it was built up during a long period of stable coastline. Deposits 3 to 7, particularly Nos. 6 and 7, are relatively low in zircon and high in rutile. They underlie a success of lower dune-ridges, formed when the coastline was advancing seawards. The differing compositions can probably be explained in terms of changing compositions of the heavy minerals migrating along the coast. The availability of sand and minerals was determined by eustatic changes in sea level. A large supply of heavy concentrate existing as a minor constituent of large volumes of sand, silt, &c., was carried to the coast by rivers during and for some time after each period of emergence, when the aluvium in the valleys was being eroded to a new base level. The material being eroded was mainly unconsolidated sediment that had been deposited there after the preceding stage of submergence. Along the coastline the heavy minerals least exposed to erosion and transport were those in the most highly concentrated parts of the seams beneath the upper portions of the beach. They were relatively rich in zircon and monazite. The more exposed parts were relatively rich in rutile, and, in lesser degree, in ilmenite, and it may be expected that the migrating minerals would approximate to them in composition. After a considerable period of stable sea level, the beach deposits near the source of supply became poorer in rutile, a little poorer in ilmenite, and correspondingly enriched in zircon.

Northwards along the coast from the source of supply the deposits were being augmented by sands transported northwards, and the impoverishment in rutile and ilmenite gave place to an enrichment in these two minerals. Through a continuation of this process of selective transport, the concentrates migrating on to a particular beach gradually became richer in zircon. The composition of deposit 8 indicates that this process had operated without interruption for a relatively long period, and it supports the suggestion already made on morphological grounds, of a long interval of stable shoreline. Deposits 7 to 3 inclusive have the composition appropriate for a period marked by renewed supplies of sediment resulting from slight emergence, and an accompanying seaward advance of the shoreline. The expected slight increase appears in the zircon-content, towards the end of the period. Deposits 2 and 1 show a sudden increase in zircon, which could not be explained as a result of an uninterrupted progress of the selective transport outlined above. Possibly other deposits which bridged the gap in composition between No. 3 and No. 2 may have been laid down, but removed by erosion before No. 2 was deposited. Alternatively, extensive deposits farther south, which had been depleted in rutile, may have suddenly become exposed to erosion and migration. These deposits could have existed as seams beneath parallel dunes stretching from Brunswick Heads to Mooball Rocks, which now form sea-stacks a few hundred feet off-shore, and from Mooball Rocks to Potts Point. Severence of the dune belt at Mooball Rocks by a meandering creek, the forerunner of Mooball Creek, would result in the rapid erosion back to the present coastline.

In other areas, a similar sharp decrease is observed in the zircon-content a short distance inland from the beach.

The figures for the Broadbeach Recreation Area, as actually determined, are given below. They suggest a series of changes in composition from the beach landwards similar to those of the Cudgen area, but the differences are so small that they could be due to random errors in boring and sampling.



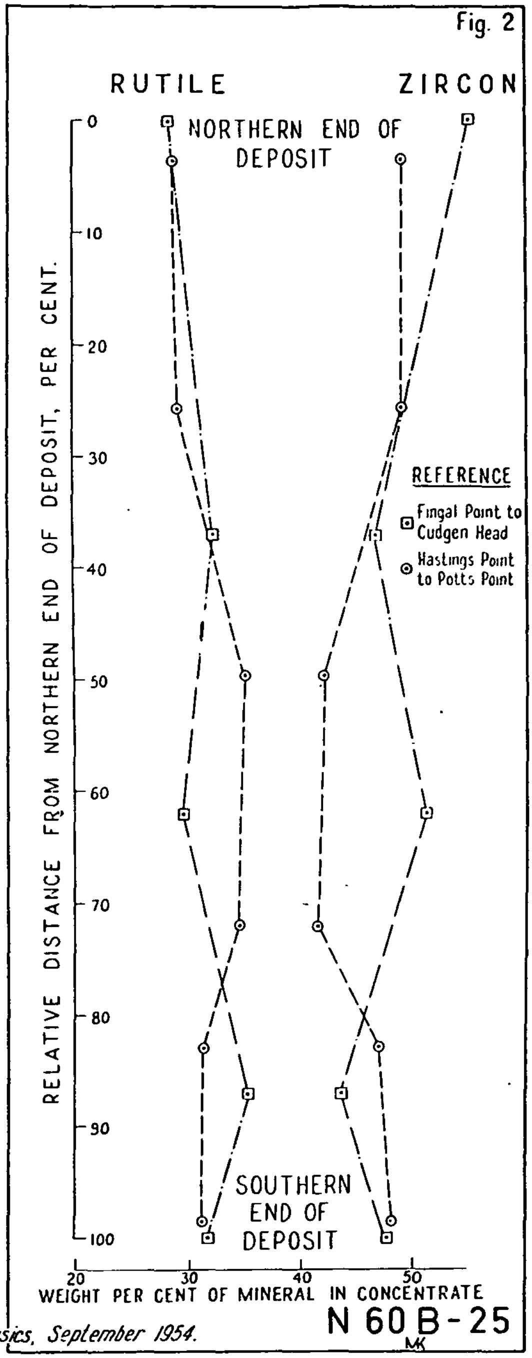


Fig. 1.—Cudgen Area. Diagrammatic plan of deposits and localities of samples referred to in tables 26 and 27.

Fig. 2.—Distribution of zircon and rutile along beaches that terminate at northern headlands.

BROADBEACH RECREATION AREA—COMPOSITIONS OF CONCENTRATES.

Distance from Beach.	Percentage Composition.			
	Zircon.	Rutile.	Ilmenite.	Monazite.
Beach to 200 ft. inland	42.3	33.4	23.7	0.54
240 ft. to 440 ft. inland	38.7	35.4	25.4	0.44
480 ft. to 550 ft. inland	36.7	35 7	27.1	0.48
820 ft. to 1,050 ft. inland	37.4	35.7	26.4	0.54

Distribution Along a Deposit.

The distribution of the heavy minerals along seams on and adjacent to beaches was investigated by taking samples from boreholes, and determining their compositions. The localities of these samples in the Cudgen Beach area are shown in Fig. 1, B to G, and their composition in Table 26.

TABLE 26.—CUDGEN AREA: VARIATION IN COMPOSITION OF CONCENTRATES ALONG THE DEPOSITS.

Sample Locality Shown in Fig. 1.	Average Percentage Composition (Neglecting Garnet and other Minor Minerals).			
	Zircon.	Rutile.	Ilmenite.	Monazite.
A	36.0	40.6	22.9	0.45
B	42.4	35.9	20.2	0.53
C	43.9	35.0	20.6	0.56
D	43.6	35.2	20.7	0.47
E	46.2	33.2	20.1	0.48
F	43.4	35.2	20.9	0.51
G	44.5	34.4	20.6	0.56

The deposit sampled at A is in a sand-spit near the mouth of Cudgen Creek from the western edges of deposits between 1300N and 15800N. Table 26 shows that zircon varies inversely as rutile. Ilmenite and monazite change only slightly; the ilmenite increases with the rutile, and the monazite is usually proportional to the zircon. The distributions of the minerals along other deposits are discussed in the sections describing the individual areas, and are summarized here. The deposits were sampled in sections from south to north, as was done in the Cudgen Beach area, and the average composition of each set of samples was regarded as representative of the deposit at the mid-point of that section. For example, the average composition of the samples from boreholes 2,000 feet and 3,000 feet south of the northern end was regarded as representative of the deposit at 2,500 feet south. Thus the distribution of minerals in a deposit was depicted by the average compositions estimated for each of several points at intervals along it from its northern to its southern end. To express the results graphically on the same scale for all deposits, the distances from the northern end in each deposit were expressed as percentages of the total length of the deposit.

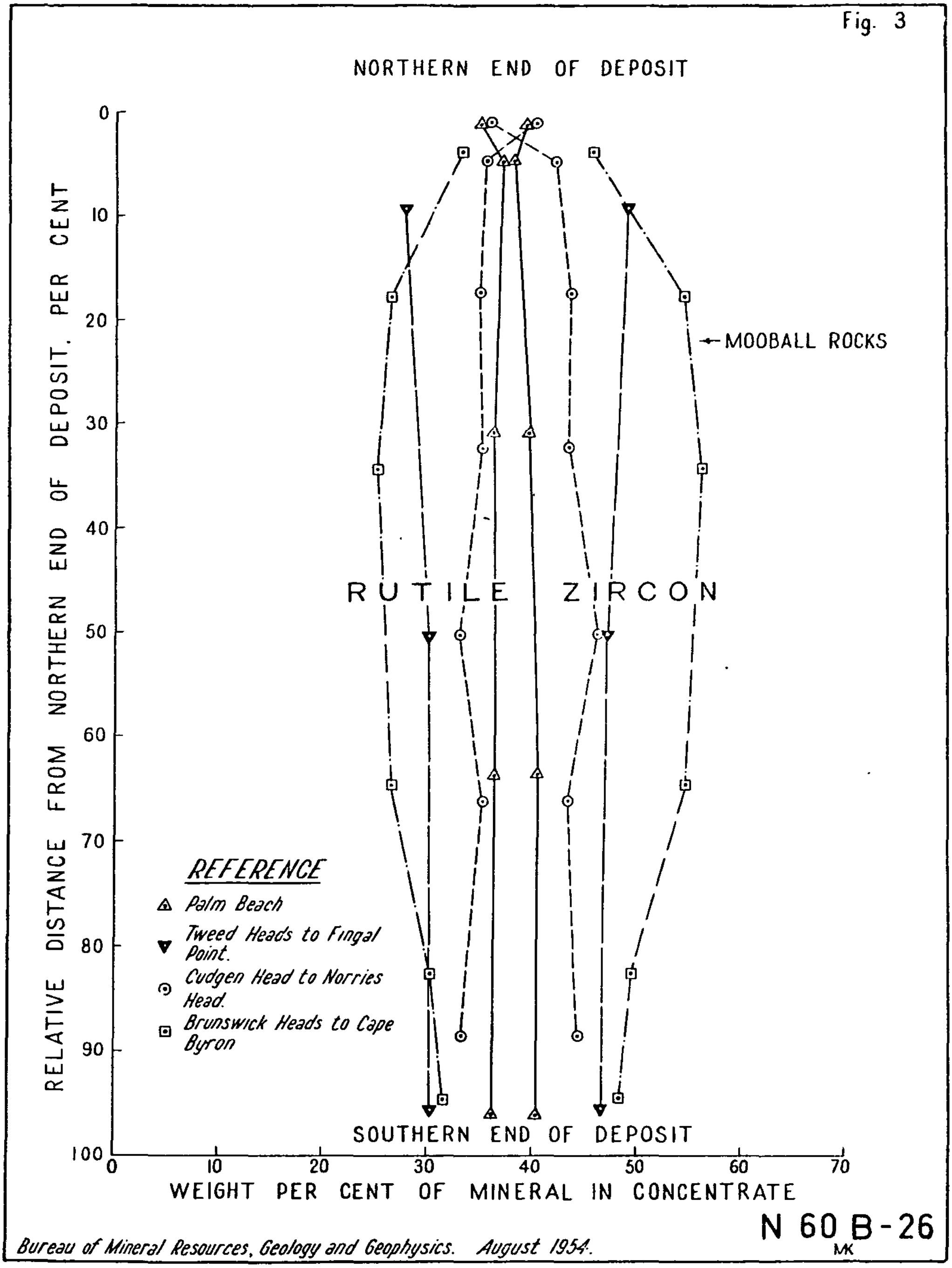


Fig. 3.—Distribution of zircon and rutile along beaches that terminate, in a northerly direction, at stream mouths.

Figure 2 is constructed to show the proportions of zircon and rutile at intervals along two beaches that terminate northerly at headlands, and Figure 3 gives the same information for four beaches that terminate at stream mouths. Ilmenite and monazite are not included because the changes in their proportions are much smaller in magnitude; ilmenite varies as rutile and monazite as zircon. In Figure 2, starting at the southern end and going northwards, the zircon and the rutile curves tend at first to approach one another, and then to diverge. This indicates that at first rutile is increasing and zircon decreasing, but that farther north the trend of the change is reversed. The deviations from mean composition are comparatively small. However, those that are observed may be explained by the processes known to be operating. There is a tendency towards depletion of rutile from the southern end by northward migration, and at the northern end by rip currents. The latter appears to be the more effective, and if the two processes continued for a considerable time, the final result should be a gradual increase in zircon from south to north. However, the main shifting of minerals, at least by the rip currents, takes place during storm periods, which are too short to enable equilibrium to be established.

In Figure 3, which gives the distribution of minerals along beaches that termnate northwards at river or creek mouths, the zircon and the rutile curves tend to approach one another slightly from south to north. This indicates a small steady decrease in zircon and increase in rutile, and is apparently the result of northward migration of rutile. The modifying influence of the rip current that occurs near a northern headland is not seen here. These patterns of mineral distribution do not apply to all beaches. In Figure 3, the curves for the beach between Tweed Heads and Fingal Point show an increase of zircon in a northerly direction, instead of a decrease. This is thought to be due to local causes, including wind-transport of minerals rich in rutile from the exposed spit, and the occurrence of a substantial breakwater at the northern end of the beach, which may give rise to a rip current. The deposits between Brunswick Heads and Cape Byron become narrow and discontinuous at a relatively short distance southwards from Brunswick Heads, and selective northward transport of their minerals must result in deviations from the distribution appropriate to a continuous deposit. Local departures from average composition are produced in several ways. An irregularity in the coast line, such as that opposite Mooball Rocks between Potts Point and Brunswick Heads, may favour the deposition of heavy minerals. It may also result in the formation of a rip current, which modifies the composition of the deposits. The heavy concentrates on a spit at the mouth of a stream usually differ in composition from those on the beaches, although they may be continuous with the beach deposits. At Cudgen Creek, the spit deposit is made up of minerals carried to it by the creek, and is high in rutile. At Palm Beach (Figure 3) the spit deposit has been derived from minerals migrating along the beach. It is higher in zircon than the adjacent beach deposits, presumably because of selective removal of rutile by the creek.

Distribution between Clarence River and Stradbroke Island.

In considering the sources of the heavy minerals in the high-grade deposits along this stretch of coast reasons were given for considering that they have been derived almost entirely from the Clarence Series sandstones in the Clarence Basin. Their present distribution is a result of their transportation at varying rates along the coast. The evidence available indicates that the supplies of minerals came in three distinct increments, each of relatively short duration, during the emergences from the +10-foot, +5-foot and +2-foot sea-levels, when the unconsolidated sediment in river valleys was rapidly removed down to new base-levels, and near-shore sediment was elevated close to or above sea level. Arranging the minerals according to their relative rates of transport from slowest to fastest, they are: zircon, ilmenite, rutile. Monazite is probably slower than zircon.

The distribution across the deposits, in a landward direction, shows that their relative rates of transport along the coast were of the same order. A quantity of heavy minerals made available by emergence, occurring actually as a minor constituent of quartz sand, would be extended gradually northwards. The northern part would be markedly enriched in rutile and slightly in ilmenite, and the southern part in zircon and monazite. Actually the supply of heavy minerals made available at each emergence continued through an interval of time during which an approximately constant composition was maintained at the source of supply, at the river mouth.

At the time of the +10-foot sea or in an early stage of the emergence that succeeded it the compositions of the concentrates near the river mouths, as reflected in deposits in nearby +10-foot heathlands, were those given in Table 27.

TABLE 27.—COMPOSITIONS OF DEPOSITS IN HEATHLANDS NEAR CLARENCE AND RICHMOND RIVER MOUTHS.

Locality.	Zircon.	Rutile.	Ilmenite.	Monazite.
Near Clarence River Mouth—Deposits known as Macaulays Lead	47	31	21	1.0
Near Richmond River Mouth—Deposits near town of Broadwater*	51	33	16	?

* Figures supplied by Mr. W. H. Derrick, Manager, Titanium Alloy Mfg. Co.. Cudgen.

The only deposits of the +10-foot level north of here are near Norries Head, about ½-mile inland. The percentage composition of concentrates from several bores in this locality is—

Zircon.	Rutile.	Ilmenite.	Monazite.
39	41	19	0.4

The increase in rutile could be expected. Comparison of the compositions of Table 28 with those of the heavy minerals in the Clarence sandstone (Table 24) indicates that the deposits near the river-mouths had been depeleted in rutile.

The +10-foot deposits at Macaulays Lead are relatively high in grade and contain about 100,000 tons of heavy minerals. The tonnage of heavy minerals near Broadwater is not known, but is thought to be much smaller, and the grade much lower. At Norries Head the tonnages are small, but there the deposits have been eroded. No heathlands of the +10-foot level are known north of Norries Head. The coast was deeply drowned during the submergence that culminated in the +20-foot sea level and, as already suggested, it probably remained a drowned coast at the time of the +10-foot sea, except for some distance northwards from the mouths of the principal streams.

Deposits of the +5-foot sea occur 1¼ miles inland from Seven Mile Beach, and at North Burleigh, Burleigh, south of North Nobby, and South Nobby. Low-grade concentrates in indurated sand of probably +5-foot heathland occur about 700 feet inland from Tallow Beach. Other heathland areas of the +5-foot level are described in connexion with the physiography of the coastal area. The compositions of the known deposits are given in Table 28.

TABLE 28.—COMPOSITION OF HEAVY-MINERAL CONCENTRATES IN +5-FOOT HEATHLANDS.

Locality.	Zircon.	Rutile.	Ilmenite.	Monazite.
Seven Mile Beach, 1¼ miles inland	46	36	17	0.8
Tallow Beach, indurated sand probably of +5-foot level, 700 feet inland	35	44	21	0.3
Burleigh, South Nobby to 1,700 ft. south, 500–800 ft. nland	30	20	50	0.1

The deposits at Seven Mile Beach and Tallow Beach show the effect on composition of the faster rate of transport of rutile. That at Burleigh cannot be so explained. The ilmenite does not appear to be derived from Tertiary basalts, because its grain size, determined by Beazley (1950), is much too large. The heavy minerals in the Tweed River sands at Uki, also examined by Beazley, contained 58 per cent. ilmenite (and 38 per cent. magnetite), and more than 90 per cent. by weight of the mineral grains had a median diameter exceeding 0.251 mm. It seems likely that the heavy minerals here were derived in part from sediment brought down by the Tweed River.

Deposits of the —5(?)-foot sea were intersected in bores put down by the Bureau of Mineral Resources at Tugun, Burleigh, and North Burleigh, but their compositions were not determined. The samples obtained at Tugun appeared to be relatively coarse-grained, and to contain a good deal more rutile and ilmenite than the usual beach-sand concentrates. Deposits at Toolena St. were reported by Mineral Deposits Syndicate, who worked them, to contain 27 per cent zircon, 27 per cent. rutile and 46 per cent ilmenite. It is likely that these and the low-level deposits at Burleigh and North Burleigh derived their excess ilmenite from the same probable source as that of the +5-foot deposits, that is, the Tweed River. The concentrates obtained from bores put down by private operators in deposits, probably low-level, near Tallow Beach, Norries Head, and Point Lookout were mixed with concentrates from overlying parallel-dune deposits, and their actual compositions are not known.

The heavy-mineral deposits formed after the final emergence of two feet occur along the entire coast. Their distribution and that of the associated dunes has been greatly modified by northward migration of sand, which has denuded the southern part of this stretch of coast, and tended to counteract erosion of the northern part. The largest quantities of heavy minerals occur between Tallow Beach and North Stradbroke Island, in particular beneath the parallel dunes at Cudgen Beach, at North Stradbroke Island, from Surfers Paradise to North Burleigh, at Tallow Beach, and from Norries Head to Hastings Point. Little of these latest deposits are found between the Clarence River and Ballina, and the coastal dunes with which they were associated have been removed almost entirely. The effects of this erosion are obvious farther north, particularly on the longer beaches where as far north as Potts Point at least the latest dunes have been greatly reduced. The shorter beaches between headlands have not been so strongly eroded. Tallow Beach, which is particularly well situated in this respect, and in addition receives little drainage from the country behind it, is backed by massive dunes that cover extensive heavy-mineral deposits. North of Potts Point the unconsolidated deposits have been less eroded, in part because of the continued transport of sand from farther south. However, the dunes and deposits of Letitia Spit between Tweed Heads and Fingal Point, and portions of those between Fingal Point and Cudgen Head, are probably the successors to earlier, more extensive ones that had been completely washed away by the Tweed River. The extensive deposits between Surfers Paradise and North Burleigh may have derived much of their heavy mineral from the breakdown of these dunes, just as those at Cudgen may have benefited from the breakdown of a dune area stretching from Potts Point to Brunswick Heads. At the time of the + 2-foot emergence, North Stradbroke Island became tied to the mainland. Large quantities of heavy minerals were transported to it and deposited on successive beaches south of Point Lookout, supplementing the deposits formed from minerals washed down from the transgressive dunes.

The distribution of the minerals along this stretch of coast has already been broadly outlined. The increase in rutile in a northerly direction does not proceed uniformly; it increases abruptly on long beaches, which have been eroded back to the positions of the older inland deposits, corresponding to those at Cudgen and Broadbeach, which were initially high in rutile.

RESERVES.

The reserves of heavy minerals are summarized in Table 29. More details, including dimensions and grade of deposit and volume and average thickness of overburden, are given in the descriptions of the individual areas. The figures for localities between Southport and the mouth of the Clarence River are based on detailed sampling by the Bureau and are considered to be accurate.

The deposits are high in grade, and the tonnages shown do not include any sand containing less than 120 lb. heavy mineral per cubic yard, or approximately 4 per cent. by weight. The average grade of the deposits is considerably higher than this. The inclusion of lower-grade sand would not significantly increase the tonnage, because the mineral-bearing sand in the beach seams is nearly all relatively high in grade. Low-grade deposits occur in dunes in North Stradbroke Island, but not on the mainland, at least between Southport and the Clarence River.

The reserves estimated for the deposits from Frazer Island to Moreton Island are based on the results of a reconnaissance investigation of the beaches by the Queensland Mines Department (Connah, 1948). The bores put down during this investigation were too widely spaced to allow accurate estimates of the quantities.

The samples obtained give a close approximation to actual composition; the tonnages stated in Table 29 are the best estimates that can be made on the available data.

The figures for Swansea, Laurieton, and Bulli to Port Kembla are of about the same order of reliability. The figures given by Zinc Corporation for North Stradbroke Island (Donaldson and Stuart, 1948) are based on less extensive boring than that done farther south by the Bureau of Mineral Resources. It is possible that more work would appreciably increase the tonnage of mineral in both the high-grade and the low-grade deposits.

TABLE 29.—RESERVES OF BEACH-SAND HEAVY MINERALS, IN TONS.

Locality.	Zircon.	Rutile.	Ilmenite.	Monazite.	Total.*
Frazer Island to Moreton Island—†					
Frazer Island, Beach	22,500	15,000	51,000	500	90,000
Inskip Point	4,100	3,200	12,400	200	20,000
Double Island Point	1,600	1,600	6,700	60	10,000
Noosa Head (Paradise Caves) ..	3,400	2,800	13,700	140	20,000
Moreton Island, Beach	7,600	5,900	19,000	300	33,000
Total, Frazer Island to Moreton Island	39,200	28,500	102,900	1,200	173,000
North Stradbroke Island—					
Beach†	12,800	14,700	14,400	100	42,000
Parallel dunes‡	156,000	156,000	282,000	2,400	600,000
Transgressive dunes‡ (low-grade deposits)	1,680 000	1,620,000	2,580,000	18,000	6,000,000
South Stradbroke Island—					
Beach§	13,600	14,000	12,000	200	40,000
Foredune	3,400	3,500	3,000	50	10,000
Parallel dunes 1,000 ft. inland‖ ..	1,450	1,800	1,700	20	5,000
Southport to Mouth of Clarence River—					
Wharf Road, Surfers Paradise to North Nobby	76,800	71,500	49,300	1,020	204,000
North Nobby to South Nobby‖ ..	9,400	7,500	5,900	160	23,000
Burleigh	9,200	6,160	10,300	200	26,000
Palm Beach	18,900	16,800	10,500	250	47,000
Currumbin (Flat Rock Creek) ..	2,850	2,600	1,650	40	7,200
Tugun	20,100	17.800	23,500	110	62,000
Tweed Heads to Fingal Point ..	23,150	13,250	10,200	285	47,500
Fingal Point to Cudgen Head ..	26,500	22,300	14,100	330	64,000
Cudgen Head to Norries Head (Cudgen Beach).. .. ., ..	260,000	223,000	136,000	3,500	630,000

TABLE 29.—RESERVES OF BEACH-SAND HEAVY MINERALS, IN TONS—*continued*.

Locality.	Zircon.	Rutile.	Ilmenite.	Monazite.	Total.*
Southport to Mouth of Clarence River—*continued*.					
Norries Head to Hasting Point** ..	101,500	62,900	43,900	750	211,000
Norries Head to Hasting Point inland††	19,500	20,400	9,600	180	51,000
Hastings Point to Potts Point ..	38,000	24,800	15,500	570	80,000
Potts Point to Brunswick Heads ..	81,600	68,200	39,300	1,140	193,000
Brunswick Heads to Cape Byron (Beach)	74,400	35,900	25,100	900	139,000
2¼ miles south, ½ mile inland ..	2,600	1,675	600	25	5,000
Cape Byron to Broken Head (Tallow Beach)‡‡	107,600	55,500	37,200	1,200	206,000
Broken Head to Lennox Head ..	11,900	6,400	4,000	180	23,000
Seven Mile Beach 1¼ miles inland ..	5,600	4,300	2,100	90	12,000
Ballina to Evans Head¶	1,900	1,350	1,150	45	4,500
Evans Head to Woody Head Beach§§	13,200	8,300	5,900	210	28,000
Macaulays Lead	41,500	27,500	19,000	850	89,500
Cement Lead .. .. }	10,000	7,000	4,900	110	{ 11,500
Jerusalem Creek, west bank }					{ 10,500
Total, Southport to Clarence River	936,700	685,200	460,000	11,700	2,185,000
Other Areas (Figures Based on Inadequate data)—					
Swansea Area	4,300	4,300	1,400	150	10,000
Laurieton Area south of Grants Head‖‖	4,000	3,900	2,000	140	10,000
Perpendicular Point to Diamond Head	9,400	7,000	3,600	80	20,000
Bulli to Port Kembla	1,900	1,850	1,200	35	5,000

* Includes small amounts of tourmaline, garnet, chromite, and traces of other minerals. † Based on reconnaissance investigation by Queensland Mines Department (Connah, 1948). ‡ Donaldson and Stuart (1948). § Estimate by J. H. Reid, Consulting Geologist, September, 1949. ‖ Estimate based on inadequate boring. ¶ Deposits 2¼ miles inland have been tested by W. H. Derrick, manager, Titanium Alloy Mfg. Co. They are thought to be small and low in grade. ** Includes 133 000 tons proved by Zinc Corporation. Their estimate of monazite is 0 1 per cent., which is exceptionally low. †† Estimated from results of boring by Alluvial Gold Ltd., relatively low in grade, and not included in total. ‡‡ Bored and sampled by Zircon Rutile Ltd. §§ 14,000 tons proved near southern end ; equal quantity estimated for northern end. ‖‖ Fisher (1953).

DESCRIPTIONS OF INDIVIDUAL AREAS.

NORTH STRADBROKE ISLAND.

General.

North Stradbroke Island was examined in a reconnaissance geological investigation by a Bureau party during January and February, 1948. Much of it has been tested for heavy minerals by Zinc Corporation (Donaldson and Stuart, 1948), who carried out a programme of scout-boring, and closer boring where warranted. Beach deposits have been tested in a reconnaissance investigation by the Queensland Mines Department (Connah, 1948).

The island is 25 miles east of Brisbane, and 3 to 12 miles east of the mainland coast. It is 23 miles long from north to south and ranges in width from about 7 miles at the northern end to 2 or 3 miles at the southern end. A plan of the island is given in Plate 9. At the time of the investigation Hayles Cruises Ltd. were conducting a tri-weekly motor launch service from Brisbane to Amity Point and Dunwich. A daily ferry service was operating between Dunwich and Cleveland on the mainland. Transport on the island was restricted by the lack of good tracks. A rough track about 10 miles long ran from Dunwich to Blue Lake; another along the telegraph line from Dunwich to Amity Point had become unusable because of washouts. A reasonably good sandy road followed the south-south-easterly trend of the dune crests from Amity to Blue Lake, and a rough track ran from Amity to Point Lookout. The ocean beach and the beach-dunes are separated from the main part of the island along most of its length by the Eighteen Mile Swamp. Access to the beach was practicable only between the northern end of the swamp and Point Lookout, a distance of 4 miles, and by way of a narrow footbridge across the swamp opposite Blue Lake, about 3 miles from its northern end. Vehicles can travel the entire length of the beach at low tide. The southern part of the island could be reached on foot from Dunwich and from Blue Lake, and by landing from a boat on the west coast.

Physiography and Geological Background.

The main part of North Stradbroke Island is formed almost entirely of transgressive dunes that rise to a maximum height of more than 700 feet. They are for the most part covered by fairly open eucalypt forest and bracken fern, although in the central, highest, parts of the island the vegetation amounts only to shrubs and scattered *Xamia*. Some localities, for example immediately north-west of Swan Bay and in places bordering the Eighteen Mile Swamp, are covered by a dense scrub. Mesozoic sandstone crops out at Dunwich on the west coast and Mesozoic rhyolite at Point Lookout in the north-east. A small area of Lower Palaeozic greenstone is visible at low tide on the west coast about 10 miles south of Dunwich. These consolidated rocks provided a buttress against which northward-migrating sand banked up, but the limits of their extension beneath the sand are not known. Immediately north of Blue Lake in the scarp facing the swamp, floaters have been found up to 2 feet square and 6 inches thick of relatively coarse-grained, well-bedded sandstone. They are lithologically different from the Mesozoic sandstone and may be younger, possibly Pleistocene, in age. The transgressive dunes terminate at a scarp on the west where they overlook Moreton Bay, and on the east where they overlook the Eighteen Mile Swamp. The western scarp has been formed through erosion by tidal currents, and the eastern is clearly an early shoreline. The swamp is fringed on the east by a narrow belt of coastal dunes, and on the north, 4 miles south of Point Lookout, it gives way to a belt of northward-trending parallel dunes.

The boundaries of the transgressive-dune areas have been traced from aerial photographs and are shown in Plate 9. The limits of advance of the dunes of the last three stages are clearly visible. The frontal boundary of the dune of the second stage in its climb up the oldest dunes is not readily recognized. However, it can be traced by the lakes, swamps, and creeks that have been formed by the impounding or diverting of water that drains down the slope of the oldest dunes. At varying depths beneath the surface, the dunes are firmly indurated, apparently by iron oxide which coats the sand-grains. The loose sand has been stripped from the surfaces of the highest parts of the oldest dunes and subsequent erosion has sharpened their peaks and gullies. They support only a scattered growth of low shrubs and heath. The scarce vegetation and sharpened relief distinguish them in aerial photographs.

At several localities along the western coast and along the scarp at the eastern edge of the transgressive dunes, and up some of the creek gullies, deposits of carbonaceous sand-rock crop out at two distinct levels. Their upper limits are between 30 and 60 feet and between 90 and 110 feet above sea level. The levels were determined by means of an aneroid altimeter, corrected from the readings of a weekly barograph stationed at Dunwich on the western side of the island. The corrections were not always satisfactory, as it was found that whenever a strong sea breeze was blowing a considerable difference existed between the pressure changes on the eastern and the western sides of the island. Probably similar differences would apply in the interdune valleys compared with the dune crests. The colour of the carbonaceous deposits varies from chocolate to black. The grains are of quartz, small in size, and sub-angular to well rounded. The pore spaces are filled with soft, black or brown, finely-divided carbon and carbonaceous matter which acts as a bonding material and forms a loosely coherent sand-rock. Making allowance for its dehydration and hardening, it resembles the deposits now forming in coastal swamps. The surfaces of the outcrops are typically riddled with what appear to be worm-holes, about 5 mm. in diameter. Many of the deposits along the scarp adjacent to the Eighteen Mile Swamp contain abundant shells of limonite which range from a foot to two or three feet in diameter. Isolated rounded shells are seen, but usually numbers of shells occur close together, and commonly adjacent shells share the one limonite wall, so that, in effect, the sand-rock is partitioned by a " boxwork " of limonite. Where the base of the carbonaceous sand is exposed, one or two approximately horizontal seams of limonite may occur in the indurated dune sand beneath.

The presence of the carbonaceous sand-rock is readily observed where some erosion is going on. Elsewhere the surface becomes oxidized, loses its carbon, and becomes a mass of grey or even white sand. Sand-rock enclosed within a limonite shell may be protected from oxidation and retain most of its carbon; thus adjacent parts of the same deposit may range in colour from brownish to grey or creamy-white, depending on the degree of oxidation.

The deposits at 90 to 110 feet occur on the eastern scarp from 7 miles south to 1 mile north of Blue Lake. In a few places an indistinct horizontal bedding is seen. Those at 30 to 60 feet were observed in Canaipa Passage about 13½ miles south of Dunwich; at a locality 3 miles south of Dunwich; in Flying Fox Gully about 3 miles north of Dunwich; in Ferny Gully, 2 miles east of Amity Point; in the creek that flows from Blue Lake to Eighteen Mile Swamp; and at localities ½ mile north and ¼ mile south of Blue Lake. At the locality in Canaipa Passage, carbonaceous sand-rock overlies current-bedded sand-rock in cliffs that rise vertically from deep water to heights of 20 to 30 feet. A section is given in Figure 4.

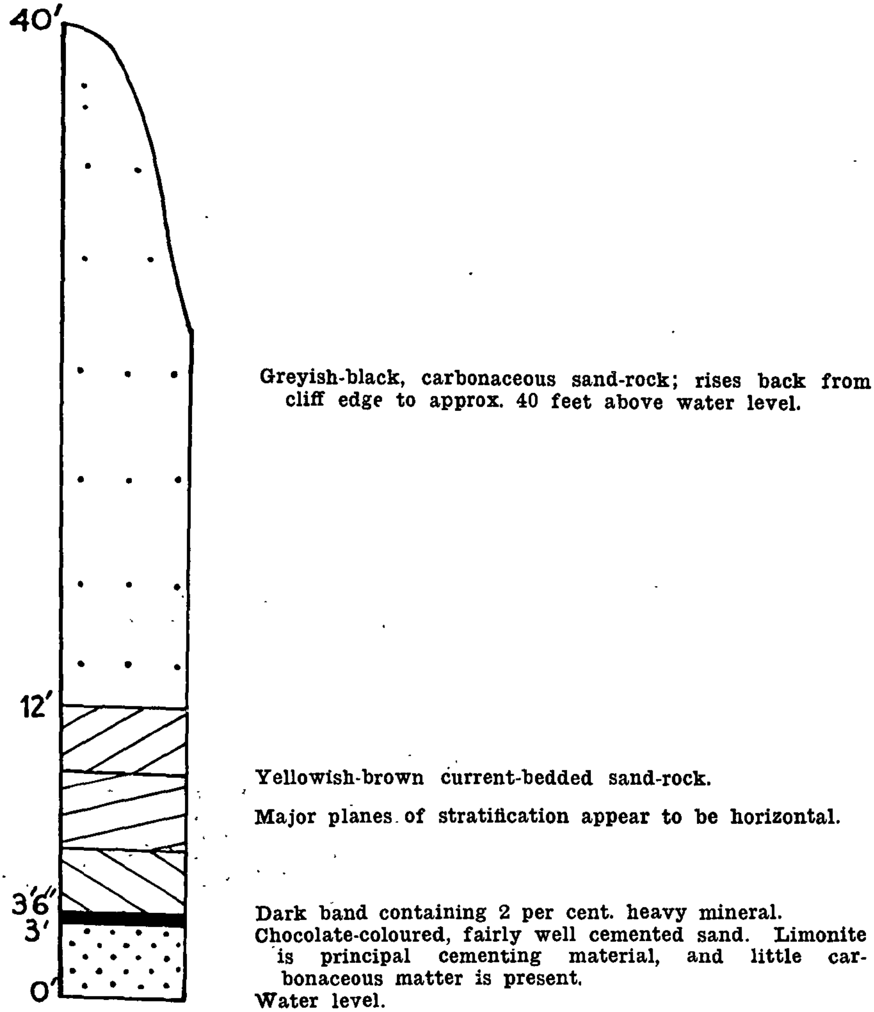


Fig. 4 Section exposed in cliff, Canaipa passage, North Stradbroke Island.

The probable origins of the carbonaceous sand and the transgressive dunes have already been discussed. Aerial photographs and the military map of North Stradbroke Island show what appears to be a scarp, partly obscured by dune sand, running in a south-south-easterly direction from about 3 miles south-south-east of Dunwich to a point near the Eighteen Mile Swamp 5½ miles south of Blue Lake. North of this scarp the five stages of transgressive dunes are seen; south of it the oldest dunes are missing, and those of the second stage, the p45 dunes, appear to have advanced as long ridges across the flat land-surface. Probably the south-south-easterly trending scarp was part of the shoreline of the +45-foot sea, and the flat surface over which the p45 dunes advanced was the emerged sea bed, formed by wave erosion of earlier p100 dunes.

Parallel dunes extend from 1 mile south of Point Lookout to the northern end of Eighteen Mile Swamp, about 3½ miles south. Others can be seen on aerial photographs from 8 miles to 10¾ miles farther south. Those in the intervening stretch have apparently been washed away by the creek flowing southwards through the swamp.

Mineral Deposits.

Deposits of heavy minerals occur on the ocean beach, beneath the parellel dunes south of Point Lookout, and within transgressive dunes of the last three stages.

Beach (*Connah,* 1948).—Deposits occur mainly within the 4-mile stretch from 13 to 17 miles south of Point Lookout. Small concentrations were found 5 to 8 miles south, but none farther north. In comparison with other parts of the coast, it could be expected that rich deposits had accumulated for some distance south of the prominent headland at Point Lookout. In the next paragraph it is pointed out that the parallel dunes from 3½ miles to 11½ miles south of Point Lookout have been washed away by the creek flowing southward through the Eighteen Mile Swamp. The present beach dunes were probably formed from quartz sand derived from the eroded parallel dunes. It may be expected that the heavy minerals would be deposited in the deepest channels eroded by the creek, and would therefore not be available for deposition on the beach.

Parallel Dunes.—Highly concentrated seams have been found beneath the northern belt of parallel dunes 1 to 3½ miles south of Point Lookout (Donaldson and Stuart, 1948). It is not known whether the southern area 8 to 10¾ miles farther south has been tested. Undoubtedly seams occurred in former times in the intervening stretch, beneath parallel dunes that have been removed by creek erosion. They may have been redistributed as deposits in creek channels beneath the swamp. A considerable proportion of the heavy minerals beneath the parallel dunes has been carried down by creeks from the transgressive dunes. The principal creek has cut a deep valley into them and has removed so much sand that the scarp, so prominent farther south, is absent here.

Transgressive Dunes.—The transgressive dunes of the last three stages from about 5½ to 12 miles south of Point Lookout contain an average of 2 per cent. by volume of heavy minerals (Donaldson and Stuart, 1948). The best samples from each of the bores put down by Zinc Corporation commonly contain more than 3 per cent. Those from bores in the p45 dunes contain less than 1 per cent. and from bores in the p100 dunes less than 0.5 per cent. heavy minerals. The heavy minerals in the later dunes have apparently been derived in large part by erosion of the p100 and p45 dunes. They have been carried by creeks to the sea shore and deposited as beach seams. It is not likely that significant concentrations will be found north of the creek that empties into the northern end of the swamp, or south of the south-south-easterly trending scarp that meets the swamp 5½ miles south of Blue Lake.

Mining Tenements.

Titanium and Zirconium Industries hold Mining Lease 313 and authority to prospect an area of 30 square miles immediately to the west of it. Mining Lease 313 embraces the parallel-dune area and the beach from the southern boundary of the camping and recreation reserve near Point Lookout to approximately 18 miles south. The authority to prospect includes the later of the transgressive dunes from the vicinity of Point Lookout to 14½ miles south. Mineral Deposits Syndicate have authority to prospect the remainder of the southern portion of the island.

Production.

Titanium and Zirconium Industries, a subsidiary of Zinc Corporation, installed a separation plant at Dunwich, and began to work the beach and the parallel-dune deposits during the second half of 1950. Approximate throughput capacity, at the time, was 720 tons heavy minerals per month.

Reserves.

The reserves are summarized in Table 30. They are all available for mining.

Beach.

The quantity of heavy minerals estimated from the results of the Queensland Mines Department investigation (Connah, 1948) amounts to 21,000 tons, having an average composition:

Zircon.	Rutile.	Ilmenite.	Monazite.
Per cent. 31	Per cent. 37	Per cent. 31	Per cent. 0.2

Allowing for beach washings during storms, and for deposits covered too deeply by overburden to be tested during the reconnaissance investigation, it appears safe to double this tonnage.

Parallel Dunes.

Zinc Corporation estimated reserves of 1,140,000 cubic yards of sand in the area bored, containing 7.6 per cent. by volume of heavy minerals (Donaldson and Stuart, 1948). It was thought safe to double this figure, giving reserves of approximately 600,000 tons of heavy minerals. The composition of samples tested by the Bureau is:

Zircon.	Rutile.	Ilmenite.	Monazite.
Per cent. 22	Per cent. 32	Per cent. 46	Per cent. 0.4

Transgressive Dunes.

The boring done by Zinc Corporation indicates reserves of 200,000,000 cubic yards containing 2 per cent. heavy mineral by volume or approximately 6,000,000 tons of concentrate. The average composition (Donaldson and Stuart, 1948) is:

Zircon.	Rutile.	Ilmenite.	Monazite.
Per cent. 28	Per cent. 27	Per cent. 44	Per cent. 0.3

TABLE 30.—NORTH STRADBROKE ISLAND: RESERVES OF HEAVY MINERALS, IN TONS.

Deposits.	Grade: lb. per Cubic Yard.	Zircon.	Rutile.	Ilmenite.	Monazite.	Total.
Ocean Beach	Probably about 500	12,800	14,700	14,400	100	42,000
Parallel dunes	about 350	156,000	156,000	282,000	2,400	600,000
Transgressive dunes ..	about 75	1,680,000	1,620,000	2,580,000	18,000	6,000,000

SOUTHPORT TO COOLANGATTA.

Introduction.

The stretch of coast from Southport to Coolangatta contains extensive high-grade deposits that have been worked by three syndicates or companies for more than ten years. It is traversed from north to south by the Pacific Highway and the Queensland South Coast Railway. The area is a popular holiday resort and the greater part of the coastal dune belt is now covered by buildings, roads, and other improvements. Large reserves of heavy minerals remain in the improved areas, and are not now available for mining. Most of the high-grade deposits outside these areas have been worked out, and production is now from annual beach washings, from lower-grade deposits, and from small portions of high-grade deposits available for mining by agreement with the owners of unimproved allotments.

Topography and Geological Background.

A plan of the area investigated between Southport and Coolangatta is given in Plate 2, and sections along bore lines in Plate 13. The low-lying coastal belt is divided into four units by ridges of consolidated rock that extend to the coast, or almost to it. Each consists of a belt of dunes adjacent to the beach, succeeded on the landward side by low-lying coastal plain, or by heathland, which, though at a slightly higher level, tends to be damp and swampy. From Surfers Paradise to North Nobby the dune belt has an average width of 1,200 feet, and is made up of at least a dozen parallel ridges. The dune belts in the other areas are narrower but several parallel ridges can be distinguished in each. They are relatively low, their crests in most places rising no higher than 25 feet above mean low water. Sections along the bore-lines that cross the parallel dunes between Broadbeach and North Burleigh show that the farthest inland of the heavy-mineral seams beneath them are slightly higher than those on and near to the beach. A glance at the section along the "Wharf Road" bore-line, given in Plate 13, gives this impression, but it is not easy to decide the actual difference in elevation. The seams intersected by the bores between 890E and 1,130E appear to have a lower limit of +3 feet, referred to mean low water. Those from 0 to 210E appear to have a lower limit of +5 feet, except the relatively low-grade material, which persists down to +3.5 feet in bore 150E. Inspection of several sections shows that the more landward seams are no less than 1 foot and no more than 2 feet above those near the beach. The lower limits of the seams between 650E and 350E in the "Wharf Road" section appear to be at an intermediate level, and this seems to be true of most of the bore-lines in this area.

The coastal plain on the landward side of the dune belt from Southport to North Burleigh is nearly all low-lying. Drains have been dug through it, and they keep the water table low enough to allow most of it to be utilized for grazing. Two small sandy areas rise several feet above the general level of the coastal plain. A bore put down in the northern one, at locality R in Plate 2, encountered indurated sand at a shallow depth. A bore in the southern area at locality S passed into coarse sand at about water level, which must have been several feet above mean low water on Broadbeach. The coarse sand is interpreted as a littoral deposit, probably of the +5-foot sea. The indurated sand is also thought to be a remnant of a +5-foot heathland, because none of the younger sands examined along the coast have been found to be indurated. It is possible that an extensive belt of +5-foot heathland once occurred in this area, and has been nearly all eroded by the Nerang River and by several creeks, notably the one that flows northwards past Mudgeeraba.

From North Nobby to Burleigh Head the dune belt corresponding with that from Broadbeach to North Burleigh is only a few hundred feet wide. Between North Nobby and South Nobby it gives way on the landward side to a flat area whose surface level is 21 to 22 feet above mean low water. It is covered by low shrubs and heath, and is traversed by slightly lower, somewhat swampy strips which, on aerial photographs, are seen to curve round like old beach-lines between the two Nobbies. The underlying sand is indurated below a depth of about 10 feet. A section along bore line 1,607S, given in Plate 13, shows deposits at a relatively high level between 560W and 720W, but they are underlain by a rocky spur that seems to extend from North Nobby, and hence they give no idea of the level of the sea which deposited them. However, similar deposits from 500W to 357W in the section of bore-line 1,263S, south of South Nobby, bottom at about 8 to 9 feet, and by comparison with the levels of the deposit in the "Wharf Road" bore-line, they appear to be about 5 feet above those on present-day beaches. The lower limit of the seam at 430W is not known, because boring was abandoned when the hard indurated sand was encountered. This association with indurated sand suggests that the deposits are older than those beneath the parallel dunes, that is, they antedate the +2-foot sea. In bore-line 1,607S at 417W and in line 1,263S from 260W to 170W the deposits continue downwards below those on present beaches, to a minimum level of at least 6 inches below mean low water, which was the lower limit of boring. They appear to indicate a shoreline at least 3.5 feet lower than the present one. By analogy with similar deposits at Tugun which have been bored to 2 feet below mean low water, and are hence at least 5 feet lower than present-day beach-seams, they have been termed the —5(?)-foot deposits. On the seaward side of these low-level deposits, in both bore-lines the seams are at levels comparable with those in the "Wharf Road" bore-line. The distinction made between the deposits on the basis of their relative levels is strengthened by marked differences in their compositions, which are shown below the section of bore-line 1,263S. The deposits at +5-feet and —5(?)-feet are extraordinarily high in ilmenite and low in zircon. Their possible derivation from Tweed River sands is suggested earlier in a discussion of the mineralogical compositions of the deposits along the coast. Of the +5-foot deposits those between 450W and 310W are noticeably higher in zircon and lower in ilmenite than the ones which preceded them, i.e., those to the west of them. This enrichment in zircon has been shown to take place during an interval of stable sea level—in this case at +5 feet. The —5(?)-foot deposits are also very high in ilmenite, and if the Tweed River has contributed much of the heavy mineral this is consistent with the composition to be expected shortly after an emergence.

The adjacent and overlapping deposits just described show that successive shorelines have existed in approximately the same positions, at levels, with respect to the present sea, of +5 feet, —3.5 feet or lower, and +2 feet. This near coincidence of the shorelines is not unexpected, because their positions were all determined by the same headlands, North Nobby and South Nobby. Landwards from the heathland belt the surface level gradually falls until the low-lying Stephens Swamp is reached. At the time of the +5-foot sea this must have been a lagoon.

At Palm Beach, the coastal dune belt is succeeded on the landward side by a long, narrow, northward-trending swamp, probably a former channel of Currumbin Creek. The northern part of the small coastal plain is made up of tidal sand flats in varying stages of reclamation by vegetation, progressing from salt-water couch and rush-like sedges to stands of swamp sheoak and paper-bark ti-tree. Farther south, the country is sandy and supports a form of open forest dominated by scrub-box and black-wood, with an undergrowth of shrubs, vine, heath, bracken, and blady-grass.

Between Currumbin and Coolangatta the coastal plain consists mainly of heathland and semi-swamp, which has a surface level appreciably higher than that of the low-lying coastal plains. A low-level swamp a few hundred feet wide intervenes between it and the coastal dune belt. On its landward side the surface slopes away slightly for some distance, and then abruptly in the vicinity of Cobaki Broadwater and nearby swamps. The section of bore-line 5,257S given in Plate 13 shows mineral deposits beneath the beach dunes, and low-level deposits on their landward side, associated with indurated sand. In a bore a little farther north, these deposits continue downwards at least to 2 feet below mean low water, where they are indurated and too hard to penetrate with the boring equipment that was used. The bottom level of these deposits is 5 feet below the bottom levels of the deposits on and near the present beach, and it is from this that the —5(?)-foot sea was deduced. No high-level deposits were found, but they possibly occur in heathland belts farther inland. On general morphological grounds, and because it is indurated, the heathland is regarded as an emerged bay-floor of the +5-foot sea, on which some low dune-ridges formed, probably as foredunes. The seaward edge of the 5-foot heathland shown in Plate 2 was the shoreline of the +2-foot sea, and the heavy minerals at 1,280W and 1,160W were deposited by that sea. The shoreline of the earlier —5(?)-foot sea was at approximately 700W, and the deposit at 705W is to be attributed to the —5(?)-foot sea. It can be seen that the +2-foot shoreline advanced a few hundred feet farther landward than the —5(?)-foot shoreline, and the low-level mineral deposits became covered with quartz sand and heavy minerals at a higher level. As at North Burleigh and Burleigh the positions of the successive shorelines were approximately fixed by the same headlands.

Mineral Deposits.

Deposits occur beneath portions of the beach dunes on all the beaches except Palm Beach, where they have been removed by erosion in recent years; in + 5-foot heathlands; and in low-level (— 5(?)-foot) seams adjacent to the seaward boundaries of the heathlands. They are shown in plan in Plates 10, 11, and 12, and sections along some bore-lines are given in Plate 13.

The beach deposits are richest and thickest at the northern ends of the beaches, particularly at Burleigh for some distance south of South Nobby, and at Tugun, south of the low headland at Flat Rock. They have been worked since 1941, and, notwithstanding seasonal regeneration during storms, the reserves on the beaches have steadily diminished. In 1950, Mineral Deposits Syndicate estimated a total approximate annual yield of 2,000 tons of concentrates in beach washings from the Spit at Southport, Broadbeach, North Burleigh, and Burleigh. Palm Beach was worked some years ago by Rutile Sands Pty., but erosion in recent years has removed most of the mineral, and caused the beach line to advance landwards until much of it is now within the boundaries of private allotments. Deposits at the northern end of Tugun Beach, worked by Rutile Sands Pty., have been repeatedly rejuvenated by storms.

The sub-dune deposits are most extensive between Surfers Paradise and North Burleigh. They are richest and thickest within 300 to 400 feet of the beach, but the seams continue landwards for another 1,000 feet, becoming smaller and less well concentrated, and separated by barren strips. Their changing composition in a landward direction—increase in rutile and decrease in zircon—has already been mentioned.

Heathland deposits have been found at North Burleigh between North Nobby and South Nobby, and at Burleigh south of South Nobby. The —5(?)-foot deposits occur at the same localities and at Tugun, adjacent to the seaward margin of the heathlands. They probably consist in part of heavy mineral re-concentrated from the earlier + 5-foot deposits, and in part of renewed supplies made available as a result of the emergence.

Mining Tenements.

The leases and authorities to prospect at the time of the investigation were as given below.

Since then, some leases have been relinquished, and other areas applied for, including the more landward deposits that are still available for mining.

The Spit, Southport:

D.C. 37. Mineral Deposits Syndicate, Southport.
D.C. 33. Associated Minerals Pty. Ltd., Southport.

Authority to prospect the Spit north of Portion 40 held by Mineral Deposits Syndicate.

Main Beach, Southport:

D.C. 36. Mineral Deposits Syndicate.
D.C. 35. Mineral Deposits Syndicate.

Broadbeach to North Burleigh:

D.C. 22. Associated Minerals Pty. Ltd.
D.C. 31. Mineral Deposits Syndicate.
M.L. 180. Mineral Deposits Syndicate.
M.L. 181. Mineral Deposits Syndicate.
M.L. Application 174. Mineral Deposits Syndicate.

Burleigh:

D.C. 23. Associated Minerals Pty. Ltd.
D.C. 15. Mineral Deposits Syndicate.
D.C. 25. Mineral Deposits Syndicate.
D.C. 26. Mineral Deposits Syndicate.
D.C. 27. Mineral Deposits Syndicate.

Palm Beach:

D.C. 19. Mineral Deposits Syndicate.
D.C. 20. Rutile Sands Pty. Ltd., Currumbin.
D.C. 21. Rutile Sands Pty. Ltd., Currumbin.
D.C. 21A. Rutile Sands Pty. Ltd., Currumbin.

Currumbin to Coolangatta:

D.L. 3. Messrs. Neumann and Casey.
D.C. 16. Mineral Deposits Syndicate.
D.C. 18. Mineral Deposits Syndicate.
M.L. 171. Mineral Deposits Syndicate.
D.C. 17. Rutile Sands Pty. Ltd.

Production.

Before 1950 the total Queensland production of beach sands minerals came from deposits between Southport and Coolangatta. Since then, a small proportion each year has been obtained from North Stradbroke Island. The production up to the end of 1952 is—

Zircon—66,414 tons.
Rutile—63,328 tons.

Monazite produced since 1947:

In high-grade concentrates—40 tons.
In low-grade concentrates—371 tons.

The ilmenite in the concentrates has been discarded because it is too high in chromite to be marketed.

The largest production has been at Broadbeach and North Burleigh, but considerable quantities have also come from Tugun and Burleigh, and lesser amounts from Palm Beach, Flat Rock Creek, Main Beach, and the Spit.

Reserves.

Little of the remaining reserves are now available for mining. Between Surfers Paradise and North Burleigh up to 2,000 tons of concentrates per annum will probably be deposited annually on beaches for several years. At the time of the investigation about 50,000 tons appeared to be available in the sub-dune deposits. This was contained in the Broadbeach Recreation Area, the Crown Land at Broadbeach, and scattered small vacant allotments. Since the investigation, about 20,000 to 25,000 tons of this has been mined in the Recreation area, D.C. 31, M.L.'s 180 and 181, and private allotments. Other allotments have been built on, and by 1953 little more than the relatively low-grade landward deposits remained available.

At Burleigh a total of a few thousand tons will probably be obtained over a period of several years from beach washings, and several thousand tons from deposits below the dunes east of the Esplanade. No heavy mineral now appears to be available at Palm Beach. The Flat Rock Creek deposits have been worked on a small scale for several years, and are probably replenished to some extent during storms. At Tugun, beach washings should provide a total of a few thousand tons over a period of several years, and portions of the low-level deposits are in non-improved ground. Work on these has been started by Mineral Deposits Syndicate since the investigation. These deposits were not intersected in bore-line 3,717S, and it is assumed that they occur between bores 559W and 1,080W. This should be tested before the estimate of tonnage given in Table 31 can be regarded as proved.

TABLE 31.—RESERVES OF HEAVY MINERALS AND DIMENSIONS OF DEPOSITS BETWEEN SOUTHPORT AND COOLANGATTA SOUTHERN QUEENSLAND.

Locality.	Dimensions of Deposit.					Overburden.		Composition.*								Total Mineral.†	
	Length.	Area.	Average Width.	Average Thickness.	Volume.	Average Thickness.	Volume.	Zircon.		Rutile.		Ilmenite.		Monazite.		Weight Tons.	Grade lb./cu. yd.
								%	Total Weight.	%	Total Weight.	%	Total Weight.	%	Total Weight.		
	Feet.	Sq. ft.	Feet.	Feet.	Cu. yd.	Feet.	Cu. yd.		Tons.		Tons.		Tons.		Tons.		
Surfers Paradise to North Burleigh—																	
Wharf-road to Peerless-avenue	8,500	764,000	825	2.0	520,000	8.5	2,173,000	37.8	42,000	34.8	38,700	24.2	26,900	0.5	570	111,200	479
Peerless-avenue to North Nobby	7,200	667,000	855	2.7	596,000	6.2	1,371,000	37.6	34,800	35.3	32,700	24.2	22,400	0.5	450	92,600	348
North Nobby to South Nobby‡§	2,800	105,000	321	4.5	160,000	6.8	241,000	41.0	9,400	33.0	7,500	26.0	5,900	0.7	160	23,000	304
Burleigh—‖																	
West of Esplanade from South Nobby to 1,730 ft. south	1,730	72,200	430	5.0	122,000	7.3	173,000	33.2	7,600	24.2	5,500	41.9	9,600	0.7	160	22,900	422
East of Esplanade, 1,400 ft. to 2,000 ft. south of South Nobby	600	11,200	200	12 0	46,000	Nil	Nil	47.0	1,600	31	1,100	21	700	1.1	40	3,400	170
Palm Beach	10,400	186,000	161	3 3	206,000	4 2	263,000	41	18,900	36	16,800	23	10,500	0.5	250	47,100	513
Flat Rock Creek	1,300	22,400	157	5.9	44,400	2.9	21,400	40	2,850	37	2,600	23	1,650	0.5	40	7,250	366
Tugun—																	
Beach and Dunes ..	5,257	115,000	196	2.5	95,000	7.3	281,000	42	9,600	32	7,300	25	5,700	0.5	110	22,800	536
Low-Level Deposit¶** ..	5,450	128,000	219	6.3	269,000	5.0	211,000	27	10,000	27	10,000	46	17,000	?	?	37,300	310
Edge of heathland ..	1,500	25,000	150	2.25	19,000	7.1	60,000	Not determined. The concentrates are probably high in ilmenite and low in zircon								1,800	213

* After separating from quartz sand, and neglecting "other minerals" such as garnet, tourmaline, and chromite which form minor proportions of the concentrates. † Including a small proportion of the "other minerals" mentioned above. ‡ Estimate of 10.000 tons for low-level deposits, included herewith, based on inadequate boring. § Overall composition assumed to be that of beach and dune deposits, and probably too high in zircon. ‖ Nearly all built on or otherwise improved; only portions of area tested. ¶ Possible reserves; *see* note in text at end of this section. ** Assumed to have composition reported by Mineral Deposits Syndicate for deposit worked at Toolena St.

TWEED HEADS TO POTTS POINT.

Introduction.

The dune belts in the area from Tweed Heads to Potts Point are largely free of buildings and other improvements, the only extensive settlements being the villages of Kingscliff, north of Cudgen Head, Fingal, a short distance north and south of Fingal Point, and Cudgera, south of Hastings Point. Access to Fingal Point and to Cudgen Head, north of the creek, is by way of bitumen roads from the Pacific Highway, a run of about 3 miles in each case. A track partly metalled continues north of Fingal Point for about ⅓ mile, but beyond this Letitia Spit is trafficable only to 4-wheel-drive vehicles. The areas south of Cudgen Creek can be reached by a metalled road from Cudgen village to the bridge about 2½ miles from the mouth of the creek. Thence, sand tracks lead northward to the sandspit opposite Kingscliff and southward to the village of Cudgera at Hastings Point. From there a metalled road runs via Pottsville to the village of Mooball on the Pacific Highway. The nearest railhead is at Tweed Heads, which is the terminus of the Queensland south coast railway. The New South Wales north coast railway passes through Mooball and terminates at Murwillumbah, which is 9 miles on a direct line to the north-west. Murwillumbah is also on the Pacific Highway and can be reached by driving southwards from the Cudgen area. The sand track leading from the bridge across Cudgen Creek is very heavy in dry weather, and at times is suitable only for 4-wheel-drive vehicles. Beach-sand mining has been carried on by three operators on and near Cudgen Beach. Titanium Alloy Manufacturing Division of National Lead Co., whose plant is opposite the creek bridge a few hundred feet from the beach, have been mining the beach since 1941. Tweed Rutile Syndicate, whose plant is a mile farther north, have been mining deposits beneath the foredune; and Cudgen R-Z, in 1950, began treating concentrates from the northern end of the beach, in a plant near the creek mouth opposite the village of Kingscliff. Outside the Cudgen area, a little mining was done by Porter and Derrick in 1939-40 immediately south of Fingal Point, and Mineral Deposits Syndicate started work on G.L. 2 a mile farther south during 1951.

Physiography and Geological Background.

A plan of the area is given in Plate 3. Features of interest are the marked northward deflection of creeks and rivers, evidence of erosion of dunes north and south of Fingal Point, the wide belt of parallel dunes and associated mineral deposits behind Cudgen Beach, and the occurrence of remnants of probable +10-foot heathland near Norries Head.

On Letitia Spit, shown in Plate 14 on a scale of 1,000 feet to 1 inch, a dune belt 150 feet wide and 20 to 25 feet high stretches unbroken along the entire length of the ocean beach. Another well-marked dune ridge of about the same width runs northwards from about bore-line 5,000S to the southern boundary of G.L. 3, where it terminates abruptly near the edge of a lagoon. The northern extension of this dune has presumably been washed away by the Tweed River when the river occupied a channel marked approximately by the lagoon. A prominent dune in the southern part of the area crosses bore-line 00 at 400W, trending north-westerly, and ends abruptly about 300 feet south of the 750N bore-line, near the nearby lagoon. This is probably the southern end of another lagoon that has been formed by river erosion. The dune belt between Fingal Point and Cudgen Head (Plate 15) shows similar evidence of erosion. Between bore-lines 1,500S and 9,000S it is much narrower than elsewhere and is fringed by lagoons on the landward side. Dune ridges several hundred feet inland from the beach occur at both the northern and the southern ends of the area. They have the curved outlines of former foredunes, and probably were at one time continuous, but the middle portion has apparently been eroded by the Tweed River. The river bank in this area is now stabilized by a stone training wall, but it must have encroached as far as the beach dunes during earlier flood periods. It is very likely that the river formed an outlet to the sea a few hundred feet south of the 6,000S bore line. The crest heights of the dunes there are much lower than 20 feet, whereas on the 7,500S line the crest height is 38 feet and on the 4,500S line it is 36 feet. This dune erosion north and south of Fingal Point moved large volumes of sand and probably also considerable deposits of heavy minerals. They may have been deposited along the coast farther north.

The dune belt behind Cudgen Beach (Plates 3 and 16) is up to 1,600 feet wide and contains as many as fifteen lines of dunes. The highest dune, that farthest inland, has a crest height of about 50 feet. The foredune adjacent to the beach is nearly as high, and apparently each reflects a long period of stable shoreline. The levels of the mineral seams beneath the dunes have already been discussed. An area of heathland showing the familiar curved trend-lines exists in the coastal plain ¾ mile to 2½ miles inland. It has not been examined but is thought to have originated as tidal flats and beaches of the +5-foot sea. If so, mineral deposits of the later —5(?)-foot sea may occur near its seaward margin.

The foredune and the inland area between Norries Head and Hastings Point (Plates 3 and 17) have been tested partly by Zinc Corporation (Donaldson and Stuart, 1948) and partly by Alluvial Gold Ltd., and the beach by the Bureau of Mineral Resources. The levels of the bores put down by the companies are not accurately known. Estimates have been made: for bores put down by Alluvial Gold Ltd. they have a probable error of about 1 foot; those made for some of Zinc Corporation's bores may be several feet out. The sections given in Plate 19 show that the surface rises to an unusually high level from about 800 feet landward from the beach. The sand is indurated at some depth below the landward foot of the foredune, and the top of the indurated layer rises to a higher level at about the locality where the surface level rises. The mineral deposits beneath the beach and foredune have a lower level approximately the same as those in other coastal dunes, and it is safe to say that they were deposited by the sea at the time of the +2-foot level, or during the recession from it. Immediately behind the foredune, and in part overlain by it and by some of the +2-foot seams, are other deposits that go down below sea level. As mentioned above, the levels of these bores are only very approximately known, and it is not possible to state how deep these low-level deposits go, but they are clearly to be correlated with the −5(?)-foot deposits of Tugun, Burleigh, and North Burleigh. The +2-foot seams may occur up to 300 feet inland from the foredunes. They are succeeded by others that go down into indurated sand, such as those at bores 7, 7 (a), and 8 in bore-line Z15. The bores did not get to the bottom of these deposits, presumably because the indurated sand was too hard, and hence their lower levels are not known. Furthermore, the collar levels assumed for the bores are only rough estimates. It is likely, however, that these seams were deposited by the +5-foot sea. As in the areas investigated farther north, the shorelines of the +5-foot, −5(?)-foot, and +2-foot seas are nearly coincident. A highly concentrated seam nearly 2,000 feet farther inland, intersected by bore C in line A121, at 12 to 22 feet above mean low water, is probably a remnant of a +10-foot deposit. This suggestion is strengthened by the occurrence of gravel or pebbles at an elevation of +6 feet in the adjacent bore B. The deposit at bore C is not indurated, although the sand 2 feet below it is. The groundwater seeping to the swamp west of it and thence to Cudgen Lake has probably leached the cementing material from it. A deposit 2¼ miles inland between Evans Head and Broadwater, near the western edge of a broad belt of heathland, resembles this one in being composed mainly of loose sand. It has probably been leached by ground-water seeping towards the adjacent low-lying country around the Richmond River.

From Hastings Point to Potts Point a belt covered by heath and low shrubs occurs between the road and Cudgera Creek. Near its northern end it is indurated at a depth of 15 feet or more. It is possible that this belt was formerly more extensively indurated, but has been leached by ground-water draining to the creek. The section of bore-line 6,000N (Plate 18) shows a well-concentrated deposit at 760W to 800W. This may go down to a greater depth below the level of induration, in which case it could be a +5-foot deposit, or it may have been deposited by the +2-foot sea on an eroded surface of indurated sand.

Deposits.

South of Fingal Point, deposits of heavy minerals are found on the beaches for varying distances beneath the dune belt in each area, and in the heathlands near Norries Head. Between Tweed Heads and Fingal Point (Plate 14) they occur beneath the dunes from about 2,000 feet south of the northern end of Letitia Spit almost to Fingal Point. The principal deposit is continuous over this distance and is within 20 to 400 feet from the upper edge of the beach. No appreciable quantities were found on the beach. Discontinuous deposits occur from about 400 feet to 800 feet west of the beach. Those in line 9,000N to 7,500N are mainly due to concentration or re-sorting by the wind, and occur mostly as low active dunes or portions of dunes. The principal deposits near the beach occur within limits of +3 feet to +11 feet above mean low water, and in places lower-grade wind-blown concentrates continue upwards from them into the dunes to a height of +21 feet. In the low-lying western part of the Spit lower-grade deposits continue down to 2 feet below mean low water. These were probably concentrated or resorted by currents in the shallow eastern part of a former channel of the river.

From Fingal Point to Cudgen Head (Plate 15) deposits occur on the upper part of the beach and for a short distance beneath the dunes from the northern end to bore-line 11,250S and from 13,975S at least to 20,390S, which was the southern limit of boring. The area beyond this was occupied by a camping and recreation reserve, and was not tested. The gap in the deposits is consistent with the supposition that the Tweed River broke through to the sea a short distance south of 6,000S. By the time the river mouth became barred, the beach for some distance south of 6,000S must have been embayed. Heavy minerals may have been transported northwards from the southern end of the embayment, and arrested near the northern end, near the 6,000S line.

The deposits on the beach and beneath the dunes between Cudgen Head and Norries Head (Plate 16), more extensive than any others on the mainland coast, have been discussed already, particularly in connexion with the distribution of the heavy minerals in a landward direction. The section of bore-line 2,000N (Plate 16) shows, as do the sections in the Broadbeach area, that the deposits farthest inland are at a slightly greater elevation than those on and near the present beaches. The lower level of the high-grade deposits from the beaches to about bore 400W ranges from +3.5 to +4.5 feet. At 120E a lower-grade concentrate was obtained down to +2 feet; but this was a 3-foot sample, and the heavy mineral may have come from near the top of it. From 1,240W to 1,520W the lower level is +6.5 feet, suggesting an emergence of at least 3 feet, and from 800W to 1,000W it is +5.5 feet, suggesting that the emergence was in two stages. Inspection of sections of all the bore-lines indicates, as do those at Broadbeach, that the most landward of the deposits beneath the parallel dunes are no more that 2 feet and no less than 1 foot above the seaward deposits. It has been suggested already that low-level deposits may occur about ¾ mile inland near the seaward edge of the heathland in the Cudgen Beach area. No testing has been done there.

Between Norries Head and Hastings Point (Plates 17, 19) thick and highly concentrated seams occur on the beach and beneath the foredune, and other rich seams of both the +2-foot and the —5(?)-foot deposits occur on its landward side. They have been mentioned in the description of the geological background of the area, as have also the remnants of the older seam, probably at +10 feet, farther inland.

From Hastings Point to Potts Point (Plates 18, 19) thick and highly concentrated seams occur on the beach and below the seaward half of the foredune. A small deposit or remnant of a former deposit occurs about 700 feet to the west, but, as noted in the description of the geological background of the area, its origin is uncertain.

Mining Tenements.

The holders of leases and special lease applications are as follows:—

Tweed Heads to Fingal Point:

G.L.3. Cudgen R-Z.

Special Lease Application—

No. 125. Cudgen R-Z.

No. 144. Tweed Rutile Syndicate.

No. 149. Tweed Rutile Syndicate.

Fingal Point to Cudgen Head:

M.L.1. A. J. Knowles.

M.L.2. Tweed Rutile Syndicate.

M.L.4. Tweed Rutile Syndicate.

G.L.2. J. Cooley.

Special Lease Applications No. 148, 157, 158, 159 were held by Tweed Rutile Syndicate.

Cudgen Head to Norries Head:

M.L.1. Tweed Rutile Syndicate.

M.L.2. Titanium Alloy Manufacturing Division, National Lead Company.

G.L.9. Titanium Alloy Manufacturing Division, National Lead Company.

G.L.15. Tweed Rutile Syndicate.

G.L.17. Cudgen R-Z.

G.L.18. Cudgen R-Z.

G.L.20. Cudgen R-Z.

Special Lease Applications—

No. 102. Cudgen R-Z.

Nos. 110, 111, 112. Tweed Rutile Syndicate.

No. 147. Titanium Alloy Manufacturing Division, National Lead Company.

Dredging Lease Applications--

Nos. 121, 122. J. A. Watson.

Nos. 130, 131, 132. E. C. Clagton.

Nos. 133, 134, 135. E. C. Clagton.

Nos. 136, 137, 138. E. C. Clagton.

Norries Head to Hastings Point:

G.L.9. Titanium Alloy Manufacturing Division, National Lead Company.

G.L.13. Zircon Rutile Limited.

G.L.16. Cudgen R-Z.

Special Lease Application No. 105. Cudgen R-Z.

Hastings Point to Potts Point:

G.L.6, 7, 8, 10, 12, 14. Metal Recoveries Proprietary Limited.

POTTS POINT TO BRUNSWICK HEADS.

Introduction.

The beach and dune-belt within which the deposits occur are practically devoid of buildings and other improvements, except at New Brighton. This allows almost unrestricted working of the deposits, but it also entails some difficulties of access. Gravelled roads run to the beach from the villages of Mooball and Crabbes Creek, which are on the Pacific Highway, a few miles west of the beach, and a bitumen road runs from the highway to New Brighton. Transport is practicable with a four-wheel-drive vehicle along parts of the dune belt, but at the time of the investigation much travelling had to be done on the beach. The New South Wales North Coast Railway runs northwards a few miles west of the beach, near the highway, and railway stations are situated at Mooball and at Crabbes Creek.

Physiography and Geological Background.

A map of the area is given in Plate 4, and plans and sections in Plates 20 and 20A. The area is fringed by a narrow belt of dunes and a beach 10 miles long comprising Mooball Beach, Crabbes Creek Beach, and New Brighton Beach. The narrow coastal plain is low lying and much of it is swampy. A sand ridge several feet above the swamp level runs southwards from Pottsville for about 1½ miles and another crosses the Crabbes Creek road about ¾ mile from the beach. A small sand-flat stretching westward from Pottsville is indurated at depth and may be a remnant of a + 5-foot heathland. The sand belt that crosses the Crabbes Creek road may be a similar remnant, and if so, low-level deposits of heavy minerals may occur a little to the east.

The dune belt is low and narrow, and presumably has been eroded on its seaward side. Mooball Creek has been continually washing sand away from its northern end, thus facilitating a steady northward migration of sand along the beach. It is quite possible that the beach and the eastern edge of the dune belt formerly ran a little farther east, out to Mooball Rocks.

Mineral Deposits.

Plans and sections of the deposits are given in Plates 20 and 20A. Seams occur in the upper part of the beach and beneath the dunes along their entire length, except for a half-mile barren stretch from ½ mile to 1 mile north of the Brunswick River mouth. The lower levels of the seams are at about mean sea level except in five of the 54 bore-lines, where heavy minerals have been recorded below mean low water. Some of these may be due to faulty logging of boreholes, but others are probably correct. Thus in the westernmost bores in lines 1,400N and 23,000N heavy mineral has probably been deposited in a channel of Mooball Creek, and in lines 28,000N and 29,000N it may have been deposited in tidal channels at the end of a spit. There is no obvious explanation for the occurrence of heavy minerals down to 1 foot below mean low water beneath the upper part of the beach on bore-line 18,000N. The richest deposits are on and near Mooball Beach, from Mooball Rocks to approximately 2 miles south. The flexure of the beach opposite Mooball Rocks suggests that a mass of consolidated rock beneath the sand has checked the northward migration of the heavy minerals.

Mining Tenements.

Mining leases are held as follows:—

G.L. 6, 7, 8, 14. Metal Recoveries Pty. Ltd.

G.L. 2, 19. Cudgen R-Z.

Special Lease Application No. 129. Cudgen R-Z.

Production and Reserves.

Deposits on New Brighton Beach and Crabbes Creek Beach and sub-dune deposits near Crabbes Creek Beach have been worked since 1942 by Metal Recoveries Pty. Ltd., of Mooball. Production to the end of 1952 totalled approximately 16,900 tons zircon and 12,300 tons rutile. The monazite has been discarded in tailings.

The reserves of heavy minerals and dimensions of deposits and overburden are given in Table 32. The deposits are practically all available for mining.

The distribution of the total tonnage on and adjacent to Mooball Beach, Crabbes Creek Beach, and New Brighton Beach is shown in Plate 4, and the average compositions in these localities are given in Table 17.

Brunswick Heads to Broken Head.

Introduction.

This stretch of coast, shown in Plate 5, includes a long beach and dune belt and low-lying coastal plain from Brunswick Heads to Cape Byron, and a shorter beach, Tallow Beach, from Cape Byron to Broken Head, backed by comparatively high dunes and by heathlands. Access to the area north of Cape Byron is gained through private property just north of the mouth of Belongil Creek. Thence, four-wheel-drive vehicles can be used on a track along the dune area. Tallow Beach and the dunes south of Cape Byron can be reached by a sand track that turns eastward from the bitumen road just south of the town of Byron Bay. Except in the vicinity of Brunswick Heads the beach and dunes are in unimproved land. The area north of Byron Bay was tested by the Bureau of Mineral Resources, and Tallow Beach and the adjacent dunes by Zircon Rutile Ltd., of Byron Bay.

Physiography and Geological Background.

Between Brunswick Heads and Cape Byron the dune belt is narrow and rises to little more than 20 feet above mean low water. Erosion on its seaward side has formed a sand-cliff at the top of the beach, which differs in two respects from those seen farther north: the uniform horizontal stratification indicative of deposition in water reaches higher up the cliff face; and the sand, although not cemented, is noticeably firmer.

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TABLE 32.—RESERVES OF HEAVY MINERALS AND DIMENSIONS OF DEPOSITS BETWEEN TWEED HEADS AND BRUNSWICK HEADS, NORTHERN NEW SOUTH WALES.

Locality.	Dimensions of Deposit.					Overburden.		Composition.*								Total Mineral.†	
								Zircon.		Rutile.		Ilmenite.		Monazite.			
	Length.	Area.	Overall Width.	Average Thickness.	Volume.	Average Thickness.	Volume.	%	Total Weight.	%	Total Weight.	%	Total Weight.	%	Total Weight.	Weight Tons.	Grade lb./cu. yd.
	Feet.	Sq. yd.	Feet.	Feet.	Cu. yd.	Feet.	Cu. yd.		Tons.		Tons.		Tons.		Tons.		
Tweed Heads to Fingal Point..	9,000+ 4,600	343,000	187	2.25	290,000	7.3	497,000	49	23,150	29	13,250	22	10,200	0.6	285	47,300	364
Fingal Point to Cudgen Head..	11,250+ 6,415	362,300	187	2.25	284,000	7.3	886,000	46	26,500	32	22,300	21	14,000	0.7	330	63,600	502
Cudgen Head to Norries Head	26,400	2,445,000	834	3.8	3,122,000	11.2	9,134,000	42	260,000	36	223,000	22	136,000	0.56	3,500	640,000	459
Norries Head to Hastings Point—																	
Estimated by Zinc Corp, for special lease No. 68 (G.L. 13) and foredune to line Z67	(G.L.13) 1,900§	131,000	620§	23§	1,000,000	Nil	Nil	47	61,200	31	39,900	22	29,300	0.1	40	133,000	299
Beach tested by Bureau ..	7,000	114,900	148	3.6	137,000	6.0	231,000	51	14,300	29	8,200	19	5,200	0.8	210	28,600	467
Area between beach and special lease No. 68 south to bore line Z67 ..	4,700	63,700	121	17.7	375,700	7.2	151,900	Not determined; probably similar to beach concentrates								49,200	294
Inland deposits tested by Alluvial Gold Ltd.‡ ..	900+ 2,900	244,800	580	23.6	1,928,000	Nil	Nil	39	19,500	41	20,400	19	9,600	0.4	200	51,000	59
Hastings Point to Potts Point	8,000	165,100	186	4.2	229,700	10.8	593,300	48	38,000	32	24,800	19	15,400	0.7	570	80,100	781
Potts Point to Brunswick Heads	48,000+ 2,000	856,900	154	3.0	867,600	4.6	1,316,000	43	81,600	36	68,200	21	39,300	0.6	1,140	193,700	500

* After separating from quartz sand, and neglecting "other minerals" such as garnet and tourmaline which are present in minor proportions in the concentrates.
† Including a small proportion of the "other minerals" mentioned above. ‡ Composition of limited number of samples. § Approximately.

The deposits on the present beach are generally at about the same level as those on other beaches; for example, in bore-lines 13,000N, 12,000N, and 6,000N shown in section in Plates 21 to 21B. In bore-line 11,000N the deposits are shown at exceptionally low levels, but the low level recorded for the ground-water points to an error in levelling. This is probably true also at 14,000N. Near the end of the spit the deposits are at a low level, but this has been observed to occur in similar environments on other parts of the coast, e.g., near the end of the Spit at Pottsville. The deposits in the dunes, immediately west of the cliff face, are at a higher level. This is seen in, for example, 13,000N, 12,000N, and 6,000N, and 2,000S, 3,000S, and 4,000S. The lowest level of the highly concentrated seams is +5 feet, in bore-line 12,000N. A 3-ft. sample containing lower-grade mineral went down to + 3 feet, but the mineral probably occurred in the upper part of it. The higher level of the deposits and of the horizontal stratification in the sand-cliffs suggests that these dunes correspond with the most landward dunes near Cudgen Beach and Broadbeach; that is, that they were formed at the time of the + 2-foot sea. The dune belt thus appears to be a remnant of a former belt whose eastern part has been eroded by the sea. Undoubtedly the transport of sand by the Brunswick River seawards from the northern end of the dune belt has been a major factor contributing to this erosion.

The coastal plain is mainly low lying and much of it is swampy. It contains narrow sandy belts about ½ mile from the beach in its southern portion and north and south of the basalt spur 2 miles south of Brunswick Heads. The country is swampy on either side of them, to east and to west. The only one that has been investigated is the sand ridge that forms the "Tyagarah Area" of Plate 21A. It is indurated at some depth beneath the surface, and contains deposits of heavy minerals over at least 1,900 feet from its northern end. When the boring was done, the datum for levels was high-water mark in the river bank nearby, which was assumed to be at mean high-water level, that is, 6 feet above mean low water. This figure may be a little low, and if so the levels shown in sections should be raised a little. The level of the deposits in the sand-spit is not clearly defined by the work that was done. In bore-line 00 they appear too low to be regarded as deposits of the +5-foot sea; but this is not certain. The sand ridge may have developed as a spit; and, as seen on the present coast, heavy minerals at the northern ends and on the landward sides of spits may be deposited in channels below mean low-water level.

The dunes and coastal plain behind Tallow Beach are sheltered from sea-erosion by massive headlands. The divide between the eastward and the westward drainage in the country back from the beach and dunes is close to the scarp that forms the landward boundary of the coastal plain, and little rain-water drainage flows into the Tallow Beach area. Under these conditions of minimum erosion the dunes and heathlands, at least those north of Tallow Creek, have been better preserved than on other parts of the coast. The creek has eroded much of the south-eastern part of the area.

The dune belt adjacent to the beach was bored and sampled by Zircon Rutile Ltd. The surface levels at the bore-sites were estimated on the basis of a contour survey done by the Bureau of Mineral Resources, but the exact positions of the bores are not known, and errors of several feet could be made where the slopes are steep. Sections have been drawn along the bore-lines, and two of them, for bore-lines BB and F, are shown in Plate 22. The section along bore-line BB shows the typical levels of the deposits beneath the dunes, except at bore 3, where obviously the level has been under-estimated. As would be expected, they indicate that the deposits were formed during the interval of the +2-foot sea, or the recession from the level.

Immediately west of the dunes are low-level deposits similar to those near Norries Head. Examples are bore 7, and probably bores 8 and 9, in line F. Because of the uncertainty of the bore levels, their lower limit in depth is not known. It is apparent that here, as at Norries Head, Tugun, Burleigh, and North Burleigh, the +2-foot sea has transgressed landward a short distance beyond the shoreline of the —5(?)-foot sea. The +2-foot shoreline is marked approximately by the landward edge of the swamp behind the dune belt. At about the latitude of bore-line BB, a hole dug into the bank overlooking the swamp showed that the sand beneath is indurated. A sample of low-grade heavy mineral (about 2 per cent. by weight) obtained from the indurated sand is much higher in rutile than that in the seams farther east. Its composition is quoted in Table 18, and in Table 29 in connexion with the distribution of minerals in +5-foot heathlands. The indurated sand extends southwards as a large area of heathland, but its northern portion is covered by irregular sand dunes. By analogy with the similar areas farther north, it is regarded as a +5-foot heathland. This conclusion is reached on morphological grounds only: no boring has been done in the heathland. Some of it may have been contemporaneous with the +10-foot sea. The irregular dunes overlying its northern part were evidently transgressive dunes formed during the recession of the sea from the +5-foot to the —5(?)-foot levels. Similar dunes cover the heathlands at Norries Head, and dunes covering the basalt near Cudgen Head, on the north side of Cudgen Creek, probably had the same origin.

Mineral Deposits.

The deposits have already been mentioned in the notes on the geological background of the area. Those between Brunswick Heads and Cape Byron are shown in Plates 21 to 21B; those in the Tallow Beach area in Plate 22. Their dimensions are given in Table 33 (p. 92). For 1½ miles south from Brunswick Heads seams occur mainly in the upper part of the beach and beneath the seaward slope of the foredune. Thence to 2 miles south they are found on the beach only. After a half-mile barren stretch, beach seams, thin and narrow, occur again from 2½ miles to 5¼ miles south. These concentrations appear on the beach during storms, but the greater part of them is probably washed back into the sea. A small deposit occurs in the "Tyagarah Area" ½ mile west of the beach and 1½ miles south of Brunswick Heads. It is described in the preceding section.

Thick, highly concentrated deposits occur on Tallow Beach and beneath the adjacent dunes, from Cape Byron to the mouth of Tallow Creek. They have already been described. The concentrates from the low-level seams obtained from the bore-holes were not kept separate from those of the overlying +2-foot deposits and it is not known whether they differ in composition. The proportion of zircon decreases in the most landward of the deposits, but this could take place in deposits of the +2-foot level, as it does at Cudgen and Broadbeach. The heathlands have not been bored, and it is not known whether any deposits occur within them apart from the sample of low-grade concentrates obtained near bore-line BB.

Mining Tenements.

Leases and special lease applications are held as follows:—

Brunswick Heads to Cape Byron:

G.L.1. Zircon Rutile Ltd.

M.L.4. Zircon Rutile Ltd.

Special Lease Applications 43, 46, 47. Cudgen R.Z.

Cape Byron to Broken Head:

G.L. 2, 3, 4, 6. Zircon Rutile Limited.

M.L. 5. Zircon Rutile Limited.

Production and Reserves.

The deposits between Brunswick Heads and Cape Byron have not yet been worked. At Tallow Beach Zircon Rutile Limited started working the beach and sub-dune deposits during 1949, concurrently with beach mining at Seven Mile Beach. Production from 1949 to the end of 1952 has been approximately 27,200 tons zircon and 19,700 tons rutile. The greater part of this has come from the Tallow Beach area. The company has produced in the same period 145 tons of concentrates averaging more than 90 per cent. monazite.

The reserves of heavy minerals and dimensions of deposits and of overburden are given in Table 33. They are practically all available for mining.

BROKEN HEAD TO LENNOX HEAD (SEVEN MILE BEACH).

Introduction.

A plan of the area is given in Plate 6. Access to Seven Mile Beach can be obtained at the northern end over a well-made road from Byron Bay to a separation plant of Zircon Rutile Limited, and near the southern end of Lennox Head village. The inland deposit, No. 4 of Plate 6, is in swampy terrain. A gravelled road from Lennox Head to Byron Bay runs northward about ¾ mile from the beach, but the track leading off to the deposit is in part sandy and partly under water in wet weather. The Pacific Highway is about 4 miles from the beach, and can be reached by a road running westwards from Lennox Head village.

Topography and Geological Background.

A beach, comparatively short, although larger than Tallow Beach, extends between two prominent headlands, the southern one being an "island" of basalt that rises from swamp. The coastal plain is marked by numerous arcuate low sand belts, probably former foredunes, up to a mile and a half inland, that alternate with narrow belts of swamp. These are succeeded on the landward side by the broad Newrybar Swamp, which receives the drainage from a relatively large area of consolidated rock to the north and west. It discharges in a southerly direction to the Richmond River, past the landward side of the southern headland. This outlet has minimized erosion in the coastal plain and apparently is the reason for the preservation of the numerous arcuate sand belts.

Except for the northernmost 1½ miles, and a small stretch near Lake Ainsworth, the usual coastal dunes do not seem to occur in this area. The foredune is composed of very recent loose white sand blown over the eroded edge of a broad relatively flat sand belt covered by heath and low shrubs. Where the top of the beach is eroded the lower part of the resulting cliff is made up of the grey sand of the exposed edge of the heath-covered flat, and the upper part of loose white sand of the foredune. The grey sand, like that exposed south of Brunswick Heads, is firmly coherent, although not indurated, and it is stratified horizontally to a greater height than on the northern beaches. The heath-covered flat is presumably an emerged tidal flat of the +2-foot sea, covered by dunes whose surface relief has been subdued by shifting of sands into the inter-dune hollows. Samples of the underlying sand taken from bore-holes contain much black carbonaceous matter. This and the heath-like type of vegetation suggest a water table close to the surface. If the water level had been high enough—above the depressions in the surface—it could have brought about the present-day subdued relief, by facilitating the shifting of sand from the dune-ridges into the intervening hollows. However, as seen in the section of bore-line 9,000N (Plate 23), the water table is now at a considerable depth, and the water-logged conditions must have applied before drainage channels developed from the broad swamp adjacent to the heath-covered belt. The drainage is now from its southern end, and is apparently permanently established. Erosion of the northern end of the heath-covered belt shows that earlier drainage was to the north. Probably it was intermittent. When water had accumulated to a considerable depth the hydrostatic pressure, assisted by the erosive action of rainwash from the northern headland, resulted in the opening of a channel at the northern end. This was later barred by dune sand. The series of events was probably repeated at intervals until the channel was formed at the southern end. The true dunes in the northernmost 1½ miles, north of bore-line 15,000N, were formed after barring of the water channel that preceded them. Those near Lake Ainsworth were formed in a similar way after barring of a channel formed a few hundred feet south of bore-line 1,000N.

Deposit No. 4 at the eastern edge of Newrybar Swamp was not completely tested because in its lower parts it was indurated and too hard to bore. The lower limits of the deposit where bores did pass through it, and the levels at which beds of pebbles were encountered, indicated that the old beach on which it was deposited is 5 feet to 7 feet higher than present-day beaches. Because of the tendency to record levels a little too high, the lower figure has been accepted as the probable one.

Scout boring at localities F and G (Plate 23) showed that the other arcuate sand belts are indurated at some depth, but no heavy-mineral seams were found, and direct evidence of the sea level at the time of their formation is not available. It is likely that they, like the sand-ridge containing deposit No. 4, were formed at the time of the +5-foot sea, or during the recession from it. It seems reasonable to assume that they antedate the +2-foot sea because the broad heath-covered belt on the east, clearly contemporaneous with the +2-foot sea, is not indurated, even though much carbonaceous matter has been deposited within it. The +2-foot shoreline was probably at about the seaward edge of the sand belt that terminates at locality G. If so, the —5(?)-foot shoreline and mineral deposits are probably a little to the east of it, beneath the broad swamp.

Mineral Deposits.

Plans and sections of the deposits are given in Plate 23 and their dimensions in Table 33 (p. 92). The emerged tidal flats which form the basal part of the heath-covered flat adjacent to the beach contain only minute traces of heavy minerals. Hence where the eroded edge of this flat forms the upper part of the beach the only possible deposit of heavy minerals is a seam on the present beach. Where true dunes occur, north of bore-line 15,000N, and adjacent to Lake Ainsworth near bore-line 1,000N, seams of heavy minerals are found beneath them.

The beach seams have been depleted by mining at their northern end. They begin about ¾ mile from the northern end and extend for nearly 5 miles as very narrow deposits, interrupted by two barren stretches each 2,000 feet long.

The inland deposit (No. 4) extends from the northern end of the sand-ridge to little more than ½ mile south. There the sand-ridge gives place to swamp, and presumably it and the mineral deposits have been eroded by the southward-flowing creek. The heavy minerals in the inland deposit are stained by coatings of black or brown carbonaceous material and probably a little iron oxide. They are much finer grained than those on and near the present beach: this suggests that the bay was shallow for a considerable distance from the shore; the waves lost much energy before breaking near the beach and the surf was able to transport only finer-grained minerals.

Mining Tenements.

Mining leases and special lease applications are held as follows:—

Seven Mile Beach:

M.L. 1, 2, 3. Zircon Rutile Ltd.

Inland Deposit:

Special Lease Applications Nos. 61 and 65. National Minerals Pty. Ltd.

Production and Reserves.

Seven Mile Beach has been worked by Zircon Rutile Ltd. since 1934, and total producton up to the end of 1948 was approxmately 29,500 tons zircon and 16,000 tons rutile. Several hundred tons of concentrates containing about 20 per cent. monazite were stockpiled. Since 1949 the greater part of the company's production has come from the Tallow Beach area.

Some years ago Mineral Sands Co. installed a table concentrating plant at the inland deposit, but dismantled it after producing a small tonnage of concentrates.

The reserves of heavy minerals, and the dimensions of deposits and overburden, are given in Table 33. Practically all the deposits are in unimproved land and available for mining.

LENNOX HEAD TO EVANS HEAD.

Introduction.

The beach and dunes from Evans Head to 2 miles north were tested by the Bureau in November, 1950, and the remainder of the area was inspected in a reconnaissance investigation on 12th April, 1951. Some information has been provided on an inland deposit by Mr. W. H. Derrick, manager, Titanium Alloy Mfg. Pty. Ltd., who bored it. As this area has not been photographed from the air, it has not been possible to supplement the limited amount of field work by photo-interpretation. The mapping that has been done (Plate 7) is based on military maps, and on the results of the reconnaissance investigation. The Pacific Highway runs through the area, following the eastern bank of the Richmond River for the greater part of the distance. The country between the river mouth and the village of Broadwater is cultivated and crossed by roads running from the highway. Between Broadwater and Evans Head much of the country is swampy. South of the high dunes near Broadwater, transport is practicable only with four-wheel-drive vehicles over an old sand track that follows the inland deposits along special lease application No. 109, and another that connects the air-field near Evans Head with an observation post on the high dunes.

Topography and Geological Background.

The main part of the area appears to be a long sand-bar or spit, that has extended the course of the Richmond River for 18 miles. The southern 10 miles of it at least is by no means recent in age. It forms a wide area of heathland and swamp well above sea-level, and terminates at the coast as cliffs of indurated sand. From 3½ miles to 5 miles north of Evans Head they rise to about 15 feet above high water. The sand is fine-grained and massively bedded, and dips slightly seawards. A short distance farther north, near the end of a road leading from Broadwater, the indurated sand rises to about 10 feet above high water, and is overlain by about 10 feet of peat, which is covered by irregular sand dunes. The level of the indurated sand rises to about 20 feet above mean low water. If it is horizontally bedded up to this height, indicating deposition in water, an emergence of 20 feet since it was laid down would be suggested. However, it is possible that the upper part of the sand is indurated dune-sand, and if so, the emergence may only be 10 feet. North of the high dunes near Broadwater an extensive sandy flat covered by trees and scrub is bounded on the military maps by the 25-foot contour. This has been interpreted as a coastal flat that has undergone the emergence apparent along the shoreline—either 10 or 20 feet. South of the high dunes, the heathland appears to be at a lower level. It contains inland deposits of heavy minerals in Special Lease Application 109, and their arcuate outline suggests a former beach there. No levelling has been done in the area and the elevations of the inland seams with respect to sea level are not known. It is thought that these heathlands, like the similar ones at Macaulays Lead south of Evans Head, were formed during the period of the +10-foot sea.

The high dunes south-east of Broadwater are presumably eroded transgressive dunes that encroached on the area during the recession from the + 5-foot sea. Similar dunes 1 to 2 miles north of East Ballina and near Tallow Beach probably formed at the same time. The peat on the beach north-east of Broadwater may indicate submergence of a former coastal area, that of the — 5(?)-foot sea, and the lagoon nearby possibly marks the shoreline of the + 2-foot sea. For about 3½ miles north from Evans Head the + 2-foot shoreline may have been about a mile west of the present one. However, little information is available on the area.

Mineral Deposits.

A small deposit on the beach from Evans Head to 2 miles north was tested by boring. The remainder of the beach was inspected on 14th April, 1951, and shallow holes were dug in it. Practically no heavy mineral was found, although highly concentrated deposits were visible at the time on other beaches. The Annual Report of the New South Wales Mines Department for the year 1896 (Munro, 1897) stated that the beach north-east of Broadwater was noted for rich storm washings ("sniggers"). Apparently they were unstable deposits and have migrated northward. The same report mentioned a deposit running southwards from a point ½ mile south-south-west of Cooks Hill, near Broadwater. It could probably be found by boring but is likely to be of low grade, and covered by thick overburden. An inland deposit in the area covered by special lease application No. 109 was bored and sampled by Titanium Alloy Mfg. Pty. of Cudgen during 1947-48. The quantities of heavy minerals are not known, but they are thought to be relatively small and low in grade.

A sand beach 1 mile long between Sand Point and Black Head, north of Richmond River mouth, contains heavy-mineral deposits on its southern half, south of a low rocky outcrop on the beach. A seam 9 inches thick in the sand cliff at the beach top continues beneath the foredune. It is possible that other seams occur beneath the dunes for a few hundred feet inland.

Mining Tenements.

North of Richmond River:

G.L. 10 (between Sand Point and Black Head). Zircon Rutile Ltd.

M.L.1 (adjacent to G.L. 10, on landward side). National Minerals Pty. Ltd.

South of Richmond River:

Special lease applications Nos. 109, 110 are held by Titanium Alloy Mfg. Pty. Ltd.

Production and Reserves.

A little gold was recovered from beach washings and from the inland deposits towards the end of the last century, but none of the other beach-sand minerals have been recovered.

The reserves in the beach deposit north of Evans Head are given in Table 33 (p. 92). They are within a Royal Australian Air Force training reserve, and are not available for mining. The reserves in the inland area held by Titanium Alloy Mfg. Pty. Ltd. are not known, but are thought to be small.

The deposits north of the Richmond River, between Sand Point and Black Head, probably contain several thousand tons.

Evans Head to Woody Head.

Introduction.

A plan of the area is given in Plate 8. The boundaries south of bore-line 16,000N were traced from air-photos. The country north of this bore-line has not been photographed, and the boundaries in Plate 8 are based on those shown on the "Woodburn" 1-mile military map, supplemented by reconnaissance traverses. The area is reached by driving over a clay-surfaced road which leaves the Pacific Highway 3 miles south of the town of Woodburn. At a point 6 miles from the highway the road forks, the northerly branch running 3½ miles to the sea and the other branch 4 miles southward along a high dune or belt of dunes that runs parallel to the coast one to two miles inland. South of the dunes the road follows a curved sand ridge that overlies a seam of heavy minerals ("Macaulays Lead"), worked late last century for gold. The northern branch of the road enters a Royal Australian Air Force bombing range, and terminates at an observation post at a high dune-peak. At about 1¾ miles north a side-road runs from it to two concrete "pill-boxes". The surfaces of the high dunes, Macaulays Lead, and the dunes adjacent to the beach are permanently dry. Elsewhere much of the country is swampy and is nearly all under water in wet weather. At the time of the investigation, a deep swamp at the end of Macaulays Lead prevented access to the southern part of the area, except along the beach. This was reached by driving through water about 1 foot deep along bore line 00, and crossing a deep channel near the beach over an improvised log-bridge. The roads as far as the Highway are extremely slippery when wet, and in parts boggy. After rain, transport by vehicle is difficult or impracticable for several days.

TABLE 33.—RESERVES OF HEAVY MINERALS AND DIMENSIONS OF DEPOSITS BETWEEN BRUNSWICK HEADS AND WOODY HEAD, NORTHERN NEW SOUTH WALES.

Locality.	Dimensions of Deposit.					Overburden.		Composition.*								Total Mineral.†	
								Zircon.		Rutile.		Ilmenite.		Monazite.			
	Length.	Area.	Overall Width.	Average Thickness.	Volume.	Average Thickness.	Volume.	%	Total Weight.	%	Total Weight.	%	Total Weight.	%	Total Weight.	Weight Tons.	Grade lb./cu. yd.
	Feet.	Sq. yd.	Feet.	Feet.	Cu. yd.	Feet.	Cu. yd.		Tons.		Tons.		Tons.		Tons.		
Brunswick Heads to Cape Byron—																	
Beach and dunes ..	11,000+ 15,000	362,600	125	3.4	411,600	3.2	383,600	54	74,400	27	35,900	18	25.100	0.7	900	139,300	758
"Tyagarah" area‡ ..	1,500	40,000	240	4.8	65,000	5.4	73,000	53	2,600	34	1,675	13	600	0.5	25	5,000	180
Cape Byron to Broken Head—																	
Tallow Beach	7,500	385,900	463	12.6	1,623,000	4.8	613,000	53	107,600	28	55,500	18	37,200	0.6	1,240	206,400	285
Broken Head to Lennox Head—																	
Seven Mile Beach ..	6,000+ 2,000+ 8,000	146,600	82	2.7	132,200	1.7	82,500	53	11,900	28	6,400	18	4,000	0.8	180	22,900	387
Inland, 1¼ miles	2,000	73,200	329	4.3	105,700	5.6	137,200	46	5,600	36	4,300	17	2.100	0.8	90	12,200	258
Lennox Head to Evans Head—																	
Sand Point to Black Head ..					Probably several thousand tons high grade mineral.						Composition not known						
Inland Deposit, Sp.L.App. 109, 110	Quantity not known ; probably relatively small							51	..	33	..	16	Not known. Probably relatively low grade				
Beach, north of Evans Head	6,000	55,600	83	1.8	34,400	2.1	38,300	43	1,900	30	1,350	26	1,150	1	45	4,500	292
Evans Head to Woody Head (4 Miles North of Clarence River)—																	
Macaulays Lead	16,000	274,300	154	5.0	459,000	10.1	925,000	47	41,500	31	27,500	21	19,000	1	850	89.500	436
Cement Lead	8,000	139,900	157	2.0	95,500	13.3	621,300	46	10,000	32	7,000	22	4.900	0.5	110	11.500	270
Jerusalem Creek, west bank	3,330	53,900	147	3.4	61,400	10.4	187,400									10,500	384
Beach	8,000+ 5,000	124,900	86	2.1	89,100	2.9	122,200	48	6,600	31	4,200	21	3.000	0.8	110	14,100	354
Postmans Lake	500	4,400	80	2.6	3,900	12.9	19,100	Composition not determined								440	253

* After separating from quartz sand, and neglecting "other minerals" such as garnet and tourmaline which form minor proportions of the concentrate. † Including a small proportion of the "other minerals" mentioned above. ‡ Figures are approximate and assume that deposit continues 500 feet north of 00 line, with same dimensions as at 00 line.

Physiography and Geological Background.

The northern and southern parts of the area have contrasting topography. In the north, high damp flats, about 50 feet above sea level, in parts swampy, extend to within about a quarter of a mile of the coast where they end at an eroded scarp. They are partly covered by massive shrub-covered dunes that reach heights, in places, of more than 200 feet. The seaward side of the scarp is fringed by narrow arcuate belts of sandy heathland, or eroded remnants of such belts. The southern part is not unlike the coastal plain, but the surface level of the swamps is higher than 20 feet, and the heathlands rise, at their rounded crests, to about 30 feet. Boring has shown that the underlying sand is indurated, both here and in the high flats and dunes of the northern portion. A seam of heavy minerals at Macaulays Lead was investigated near the end of the last century by the New South Wales Mines Department (Munro, 1897), who showed that the auriferous bottom layer was 11.6 feet above high-water mark. This is confirmed by the section of the Bureau's bore-line 8,000N, shown in Plate 24. The seam, and the old beach on which it was deposited, are very close to 10 feet above the seams on present day beaches. Macaulay's Lead thus marks the position of an old beach that terminated at about the locality of the 24,000N bore-line, against a headland either of indurated sand, or of Mesozoic sediments covered by indurated sand. A deep bore put down from the crest of the sand dune about a quarter of a mile from the beach bottomed in white clay, which is regarded as the weathered Mesozoic shale. The records of the bore have been lost, and the level at which the Mesozoic sediment was found is not definitely known, but it is thought to be about 30 feet above mean low water. In bore-line 32,000N a bore 3,000 feet west of the beach bottomed in white clay at an elevation of +45 feet. The high sand dunes in the northern part of the area must have originated before the heathlands of the southern part, because no major dune-building has taken place since then. It is concluded that the dunes were formed during the preceding major emergence, that which succeeded the +45-foot sea level. The high-level flats in the northern half of the area may represent a coastal plain that formed during the time of the +45-foot sea.

The edge of the scarp probably marks approximately the position of the Mesozoic sediments underlying the indurated sand, such as those outcropping opposite bore-line 56,000N. If so it also marks the limit of any rapid landward advance of the coastline. The section of bore-line 2,000N in the Postmans Lake area (Plate 26), a little north of scout bore-line 32,000N, indicates that the lower level of deposits there is about +12 feet, and they were probably formed at the time of the +10-foot sea. In places along the edge of the scarp—between 24,000N and 32,000N, north of 48,000N, and between Schnapper Rocks and Evans Head—belts of heathland occur at a lower level than the high flats, but a good deal higher than the +10-foot heathland. They may represent emerged littoral deposits of the 20-foot sea. The present coast is marked by many discontinuous outcrops and cliffs of indurated sand. They do not occur at bore-lines 32,000N and 56,000N, rise to only +2 feet on line 40,000N, and to +6 feet at 48,000N. It is likely that at the times of the +5-foot and +2-foot seas, the higher outcrops existed as stacks, and the shore-line was at about the position of the scarp at the shoreward edge of the high flats. Stonier (1895) reported a raised beach about 6 feet above ordinary high water, apparently near the Postman's Lake area. This may be a beach of the +5-foot sea.

Farther south, from about 11,000N to 24,000N, the coastline is formed in cliffs of indurated sand and is impassable for vehicles. The indurated sand, where examined at 11,000N, rises to 19 feet above mean low water. For several feet above the beach, it appears to consist of horizontal beds or layers a couple of inches thick. The horizontal bedding shows that the sand was deposited in water, but no doubt it is covered by dune sand, or merges upwards into dune sand, which should be recognized by an aeolian type of bedding, if not by fineness of grain. This distinction was not noticed, partly because it was not sought, and partly because the indurated sand is brown and soft at some height, because of sub-surface weathering, and has lost its structure. The height of the indurated sand suggests that it could have emerged 20 feet. However, the occurrence of the +10-foot heathland on its landward side makes it more probable that the emergence was only 10 feet, although of course it could have existed as an island or stack at the time of the +10-foot sea. It may be worth recalling that the indurated sand near Broadwater, north of Evans Head, was thought to indicate an emergence of 20 feet. The occurrence in this area south of Evans Head throws doubt on that interpretation.

Mineral Deposits.

Deposits on the present beach are small and discontinuous. They occur from 1½ miles to 4 miles north of the southern end (Plate 25), and within the northernmost 4 miles between outcrops of indurated sand which act as barriers to their northward migration. The northern deposits have been intersected by bore-lines 40,000N and 48,000N (Plate 27), where they are seen to be narrow seams in the upper part of the present beach. The adjacent dunes bored along the scout lines do not contain any deposits.

The most extensive deposit in the area is on the 10-foot raised beach at Macaulays Lead (Plate 24). It has a length of 3 miles, and for most of the distance underlies a low narrow arcuate belt of heathland. This could well be regarded as a foredune formed along the beach on which the heavy minerals were deposited. Its southern end has been eroded, probably by the Esk River, but by extending it in plan southwards, it can be seen to have formerly terminated at about Woody Head. However, south of bore-line 4,000S, the deposit begins to diverge slightly from the heathland, and at 8,000S is beneath the adjoining semi-swampy country. The beach on which it was deposited had a larger radius of curvature than the heathland belt and terminated probably near Yamba Head about 5 miles south of Woody Head. The Richmond River mouth must then have been between Angoorie Point and Yamba Head.

Macaulays Lead deposit north of bore-line 1,000N has been eroded by former channels of Jerusalem Creek, but continues farther north as "Cement Lead" and "Jerusalem Creek west bank lead". These are shown in Plates 8 and 26. Carne (1895) describes the latter as the "Coolgardie Lead" and states that several distinct runs of auriferous sand were proved in the swamp. Presumably these are a short distance landwards from the bore-lines shown in Plate 26. Munro (1897) showed in his plan of the area the "New Lead" a short distance west of Macaulays Lead between the positions of the Bureau bore-lines 6,000N and 10,000N.

Several deposits like that at Postmans Lake (Plate 26) probably occur along the edge of the scarp that forms the seaward boundary of the high flats and dunes. Carne (1895) stated: "All the workings from the high levels back from the beach have been in loose white sand". They may well have been mined out for gold, and the residues containing the other heavy minerals dumped in the swampy areas adjoining.

The shoreline at the time of the —5(?)-foot sea was probably in about the same position as it is now. The indurated sand along most of the coast is higher than it could have been if the —5(?)-foot sea had advanced farther than the present sea. On the other hand, deposits of peat occur along the beach, down to at least mean low water, notably in the southern part of the area.

Mining Tenements.

Practically the whole area is held by Rucon Ltd. under the following leases or special lease applications:—

G.L.10, G.L.19, G.L.20.

Special lease applications—

111, 112, 113, 114, 115, totalling 428 acres.

32, 33, 34, totalling 175 acres.

Production and Reserves.

The area was worked between 1890 and 1900 for gold, platinum-group metals, and cassiterite, which occurred in a narrow band in the more highly concentrated part of the heavy-mineral seams. The Société Industrielle Francaise des Sables Metallifères attempted to dredge the deposits for the same minerals and monazite between 1905 and 1910, but were unable to operate profitably. Rucon Ltd. produced about 200 tons of concentrates by tabling during 1950, and stockpiled them with the intention of separating zircon, rutile, and monazite later when a suitable plant had been constructed. However, serious difficulties had to be overcome, including the treatment of stained minerals, access to the area during wet weather, and obtaining suitable workmen.

The proved reserves are given in Table 33. They are all available for mining. Probable reserves not included in the table are several thousand tons along the northern part of the beach, and an equal amount in deposits a little west of "Cement Lead" and in the "New Lead".

FRAZER ISLAND TO MORETON ISLAND.

The coast from Frazer Island to Moreton Island was examined by the Queensland Geological Survey in a reconnaissance investigation during 1947. The results of the work are described by Connah (1948) and Morton (1948). The area includes Frazer and Moreton Islands and the intervening part of the mainland coast, and Bribie Island, which is separated from the mainland by a narrow channel just north of Moreton Bay. Frazer and Moreton Islands and much of the mainland coast north of Noosa Head are composed of high transgressive dunes, that form precipitous cliffs at or a short distance back from the beaches. Parallel dunes similar to those on North Stradbroke Island do not occur, although narrow fringes of low dunes have been formed at the foot of some of the beach cliffs. The mainland coast south of Noosa Head is covered by narrow belts of lower dunes, and south of Point Cartwright much of the coastal area is swampy. Bribie Island is low and sandy, and contains some low parallel dunes in its north-eastern portion.

Mineral deposits, relatively small in comparison with those on Stradbroke Island and farther south, occur on portions of the ocean beaches, generally southwards from headlands, and probably continue beneath some of the low dunes. The reconnaissance investigation made by the Queensland Geological Survey was not sufficiently detailed to allow of a reliable estimate of the reserves. However, a summary of the occurrence of the deposits and a rough estimate of the reserves is given in Table 34.

TABLE 34.—FRAZER ISLAND TO MORETON ISLAND: OCCURRENCE OF HEAVY MINERAL DEPOSITS AND ESTIMATE OF RESERVES.

Locality.	Composition in Weight Per cent. and Reserves in Tons.				Reserves. (Tons).
	Zircon.	Rutile.	Ilmenite.	Monazite.	
Frazer Island	25	17	57	0.6	..
Indian Head to 2½ miles south ..	22,500	15,000	51,000	500	90,000
Deposit 2½ miles long, average 120 ft. wide, thickness up to 3.5 ft., averages 1.5 ft.; overburden 1 to 4 ft.					
Smaller black sand concentrations at Waddy Point, Middle Head, and a few miles north of Indian Head; recent beach washings north of Hook Point					
Inskip Point Beaches	21	16	62	1	At least
To 6 miles south and 1½ miles west ..	4,100	3,200	12,400	200	20,000
Surface concentrations up to 2 ft. thick but tapering out rapidly seawards					
Double Island Point	16	16	67	0.6	At least
To 1 mile south	1,600	1,600	6,700	60	10,000
Deposits 1 to 4 ft. thick, beneath frontal dunes about 12 ft. high. Proved width 60 ft.					
Noosa Head	17	·14	68	0.7	..
From Paradise Caves to ¾ mile south ..	3,400	2,800	13,700	140	20,000
Deposits beneath frontal dunes; about 50 ft. wide, 2 to 6 ft. thick; overburden at least 6 ft.					

TABLE 34.—FRAZER ISLAND TO MORETON ISLAND: OCCURRENCE OF HEAVY MINERAL DEPOSITS AND ESTIMATE OF RESERVES—*continued*.

Locality.	Composition in Weight Per cent. and Reserves in Tons.				Reserves. (Tons).
	Zircon.	Rutile.	Ilmenite.	Monazite.	
Point Arkwright to Caloundra Head ..	Deposits too small and too low in grade to be of commercial value				
Bribie Island	Beach washings occur on island but no significant deposits reported beneath the parallel dunes				
Moreton Island	23	18	58	0.9	..
Deposits at following distances south from Cape Cliff— 0 to 1 mile; 2 to 4½ miles; 5 to 5¾ miles; 7¾ to 8¾ miles; 13 miles to 15 miles	7,600	5,900	19,100	300	33,000

Best concentrations up to 5 miles south. Width of deposits less than 60 ft.; thickness up to 3 ft., but usually less than 1 ft.; maximum overburden 6 ft. Generally less than 1 per cent. mineral in transgressive dunes, but a small area trending north-north-west 5½ miles south of Cape Cliff (Donaldson and Stuart, 1948) averages more than 2 per cent. by volume.

SOUTH STRADBROKE ISLAND AND NORTH LABRADOR.

South Stradbroke Island (Plate 9) is separated from the mainland on its western side by the Broadwater, and at its southern end by the Nerang River mouth. Undoubtedly the southern end was formerly continuous with the mainland, and the Nerang River then flowed northward through the Broadwater. Its northern end was continuous with North Stradbroke Island until 50 years ago, when tidal currents eroded a passage to the sea at Jumpinpin. Since then a reduction in the outflow of tidal waters at the southern end of the Broadwater through the Nerang River mouth has resulted in erosion of the southern end of the island, and deposition of large quantities of sand in the Broadwater. Concurrently, the Spit at Southport has extended an equal distance northwards.

The island consists of a belt of dunes adjacent to the ocean beach, and lower dunes and sandy flats west of them. The beach dunes were formerly covered by vegetation, but they are now being wind-eroded, and loose sand is moving in a north-north-easterly direction, killing the plant-cover and encroaching on the country to the west. The western side of the island has been eroded by tidal currents, and the former channels now appear as swamps, or form portions of the Broadwater. Low parallel dunes occur immediately east of the active dunes, at least from about the mid-latitude of the island to 3 miles north. They were tested by reconnaissance boring and found to overlie discontinuous deposits of heavy minerals, the most extensive of which lies between bore-lines 10,000N and 12,500N. Deposits appear on the beach after storms, and extend for a short distance beneath the foredune. J. H. Reid, consulting geologist, estimated total reserves of approximately 40,000 tons in 1949. Insufficient boring has been done to prove the reserves in the other deposits. They are comparatively small, but it appears safe to assume that at least 10,000 tons occur beneath the foredune and 5,000 tons beneath the parallel dunes.

The North Labrador area is mainly low lying and swampy, but two low sand-dunes trend northwards about ½ to ¾ mile from the Broadwater, and another, lower lying and apparently eroded, at the edge of the Broadwater. The inland sand ridges were tested to ground-water level by the Bureau, and by Alluvial Gold Ltd. in five bores put down to depths ranging from 40 to 70 feet. The low sandy belt at the edge of the Broadwater was tested by the Bureau in collaboration with Mineral Deposits Syndicate. Little heavy mineral was recovered from any of the samples. The inland sand ridges have not been levelled, but by analogy with similar indurated areas farther south, they are regarded as emerged foredunes of the +5-foot sea. The shorelines of the —5(?)-foot sea must have been farther east, perhaps beneath the present Broadwater.

THE SPIT, SOUTHPORT.

As mentioned in the description of South Stradbroke Island, the Spit has developed during the last 50 years, apparently from sand derived from the beaches south of it, as far as North Burleigh. Washings on the beach after storms have been yielding about 1,000 tons per annum of concentrates. The remainder of the Spit has been sampled by Mineral Deposits Syndicate in association with the Bureau and shown to contain only small reserves of low-grade concentrates. A minor quantity of relatively high-grade concentrates extends some distance beneath the dunes within 300 feet of the surf pavilion, near the southern boundary of Portion 40.

LAURIETON AREA.

The coastal area in the vicinity of Laurieton was briefly examined early in 1953 (Fisher, 1953). From Diamond Head past Camden Head to Grants Head, 12 to 21 miles north of the mouth of the Manning River, the coastline is made up of two beaches 5½ miles and 2½ miles long, which curve around between the headlands. The entrance to Camden Haven Inlet, which drains Queens Lake at Watson Taylors Lake, is at the southern end of the northern beach. On the landward side of the beaches are the usual dune belts succeeded by swampy areas 1 to 2 miles wide, and these are succeeded by coastal lakes. About 1 mile south of Grants Head a spur of consolidated rock projects eastwards into the coastal plain to within about ¼ mile of the beach, and from it a belt of flat heathland and swamp at a comparatively high level, about 30 feet, stretches northwards to the spur that terminates at Grants Head. Bores put down in the heathland near its eastern margin encountered indurated sand at a depth of about 3 feet. On its seaward side the heathland is succeeded immediately by the coastal dunes, which appear to have an average width of no more than 600 feet. South of the heathland and the consolidated rock at its southern end, the country on the landward side of the coastal dunes is low lying and swampy, but it gives way to another sandy area on the eastern side of Queens Lake, which is about 1½ miles inland.

Between Camden Head and Diamond Head the belt of parallel dunes ranges up to 1,000 feet wide. It is succeeded on the landward side by a low-lying and swampy area about ⅓ mile to 1 mile wide, which leads directly to Watson Taylors Lake and to Camden Haven Inlet, a tidal channel running northwards from the lake.

If the area is compared with similar ones farther north, it appears likely that the heathland represents emerged tidal flats and dunes of the +5-foot sea, and the coastal dune belts are those formed during the recession of the sea from the +2-foot levels. The lakes probably represent areas that were scoured out to sea level at the time of the —5(?)-foot sea, and later closed by sand bars during the interval of the +2-foot sea, or the recession from it.

Mineral deposits were investigated on the beach south of Grants Head and in the parallel dune area south of Camden Head. The beach deposit is within the upper part of the beach, and continues beneath a berm about 50 feet wide at the foot of the foredune. It extends for at least 1,400 feet southwards from Grants Head, has an average width of 60 feet, and maximum width of 120 feet, and is up to 3 feet thick. The estimated reserves in it total 4,500 tons, which have the following composition, neglecting 1.9 per cent. of tourmaline, garnet and other minerals:—

Zircon.	Rutile.	Ilmenite.	Monazite.
40	39	20	1.4

About 1 mile south of Camden Head exploratory bores that were being put down by North Coast Minerals Ltd. intersected a seam between the foredune and a very high parallel dune about 300 feet from the beach. A borehole at the foot of the high dune passed through a 1-foot seam 11 to 12 feet deep containing 55 per cent. heavy mineral. Another hole, 60 feet to the east, passed through 4 feet 6 inches of heavy mineral from 9 feet to 13 feet 6 inches deep, of which the bottom 2 feet 6 inches contained 40 per cent. heavy mineral. The composition of the heavy concentrate recovered from the two bore-holes, neglecting 1.5 per cent. of tourmaline, garnet and other minerals is:

Zircon.	Rutile.	Ilmenite.	Monazite.
47	35	18	0.4

Other deposits are reported to occur along this part of the coast, e.g. at Diamond Head, and it is possible that low-level deposits exist near the eastern margin of the heathland.

Other Areas.

Clarence River to Sydney.

No systematic investigation has been made on this section of the coast. Its reserves of heavy minerals are thought to be very small in comparison with those between Tallow Beach and North Stradbroke Island. The different types of coastline shown on military maps have been classified below and notes given on the possible occurrence of deposits of heavy minerals.

PORT MACQUARIE TYPE OF COAST.

Near the principal streams wide coastal plains are developed, fringed by long beaches and coastal dunes. Beach deposits have been reported between the Macleay and Hastings rivers and others in the Laurieton area are described above. Portions of the coast which may be regarded as of the Port Macquarie type are—

Nambucca to Farquhar Inlet (100 miles);
Hallidays Point to Tuncurry (9 miles).

Carne (1896) mentioned the occurrence of heavy-mineral seams at the following localities:—

Harrington Inlet, at the mouth of the Manning River. Seams ranged in thickness from 4 to 15 inches.

Tacking Point Beach. This is presumably the beach immediately south of Tacking Point, 3 miles south of Port Macquarie; thickness of seams not recorded.

Farquhar Inlet, at the entrance to the south channel of the Manning River, 75 yards back from the beach. The black-sand layer exposed at a depth of 7 feet averaged 10 to 13 inches thick.

Leases are held as follows:—

Macleay River to Hastings River:

Special lease applications—
No. 131. L. W. Kirton.
Nos. 99, 101, 102. Mineral Deposits Syndicate.
Nos. 110 to 116. „ „ „
Nos. 193 to 195. „ „ „
No. 204. „ „ „

Hastings River to Manning River:

M.L. 12, 13. Zircon Rutile Ltd.

Special lease applications—
No. 87. F. O'Sullivan.
No. 78. A. G. Boggis & O. Gumb.
No. 74. „ „ „ „ „ „
No. 84. G. H. and J. A. Watson.

MYALL LAKES TYPE OF COAST.

Lagoons and lakes are barred from the sea by comparatively narrow areas of sand dune and swamp, fringed by sea beaches. This type of coast occurs from—

Tuncurry to North Head of Port Stephens (46 miles);
Hunter River to the Entrance, Tuggerah Lake (34 miles).

In the latter section, near Swansea, National Minerals Pty. Ltd. are working deposits at Caves Beach (Hams Beach) and Catherine Hill Bay. They are small but have been repeatedly regenerated during storms. Carne (1911) mentioned beach sand accumulations of heavy minerals near Seal Rocks. Presumably this is near Seal Rocks Lighthouse, Sugarloaf Point, east of Myall Lake.

Leases are held as follows:

Charlotte Head to Sugarloaf Point:
Special lease application—
Nos. 80 to 83. National Minerals Pty. Ltd.,

Lake Macquarie to Tuggerah Lake:
M.L. 34. National Minerals Pty. Ltd.,
Catherine Hill Bay Beach, Moon Island Beach — Worked by National Minerals Pty. Ltd., by arrangement with holders of coal leases.
Special lease applications—
796, 797. National Minerals Pty. Ltd.,
755. M. T. Weatherall and others.

WOOLI TYPE OF COAST.

Small and narrow coastal plains intervene between highlands or plateaus and the sea, and they are fringed by sandy beaches and minor coastal dunes. This type of coastline appears from—

Angaurie Point to Wooli (28 miles)
Farquhar Inlet to Hallidays Point (8 miles).

At Wooli, 11,000 tons of concentrates were produced by Porter and Derrick between 1935 and 1939. Probably any deposits found on this type of coast will be small.

Lease M.L.39, north of Angaurie Point is held by Tweed Rutile Syndicate.

Special Lease Application No. 77, north of Wallabi Point, is held by Mineral Deposits Syndicate.

Sections of coastline transitional between the Wooli type and the Woolgoolga type described below are—

Wooli to Yarrawharra (13 miles).
Coffs Harbour to Hungry Headland (16 miles).

Leases in these sections are:

Special lease applications—
No. 305. W. E. Fitzpatrick.
Nos. 60, 61(?). W. S. McColl.
No. 86. L. W. Kirton.

WOOLGOOLGA TYPE OF COAST.

Highland or plateau country extends practically to the sea and little or no coastal plain is developed. Much of the shoreline is rocky but short beaches occur between headlands. This type of coast appears from—

Yarrawharra to 2 miles north of Coffs Harbour (15 miles).

Hungry Headland to Nambucca (8 miles).

South Head to Port Stephens to Cemetery Head (9 miles).

The Entrance, Tuggerah Lake, to Collaroy Beach Townsite (30 miles).

Deposits on this type of coast are probably small. At Woolgoolga, 4 miles south of Yarrawharra, 1,997 tons of concentrates were produced in 1943-44. Minor deposits are known at Terrigal and Collaroy but no appreciable tonnages could be obtained from them.

Leases are held as follows:

Special lease applications—

No. 300. D. W. McLean.
No. 304. " " "
No. 173. W. S. McColl.
M.L.1. R. Johnson (abandoned).

South Coast of New South Wales.

Towards the end of 1952 a reconnaissance was made of the coastal area between Batemans Bay, about 120 miles south of Sydney, and Bulli, about 25 miles south. It was limited to inspection of beaches and dunes and sampling beaches by means of shovel holes. The only localities where heavy minerals were found in sufficient quantities to be possibly worth working were at Shellharbour and Bellambi. At the former locality small accumulations of wave-concentrated minerals, comparatively low in grade, appeared on and near the beaches. These were later sampled, and abandoned, by Mines Management Pty. Ltd. At Bellambi beach, a 6-in. seam at the foot of the low foredune, where sampled, contained 667 lb. heavy mineral per cubic yard. The area is held under lease but the reserves are probably only of the order of 1,000 tons or so of heavy mineral. Other small concentrations are known to occur at Port Kembla and near Austinmer.

ACKNOWLEDGMENTS.

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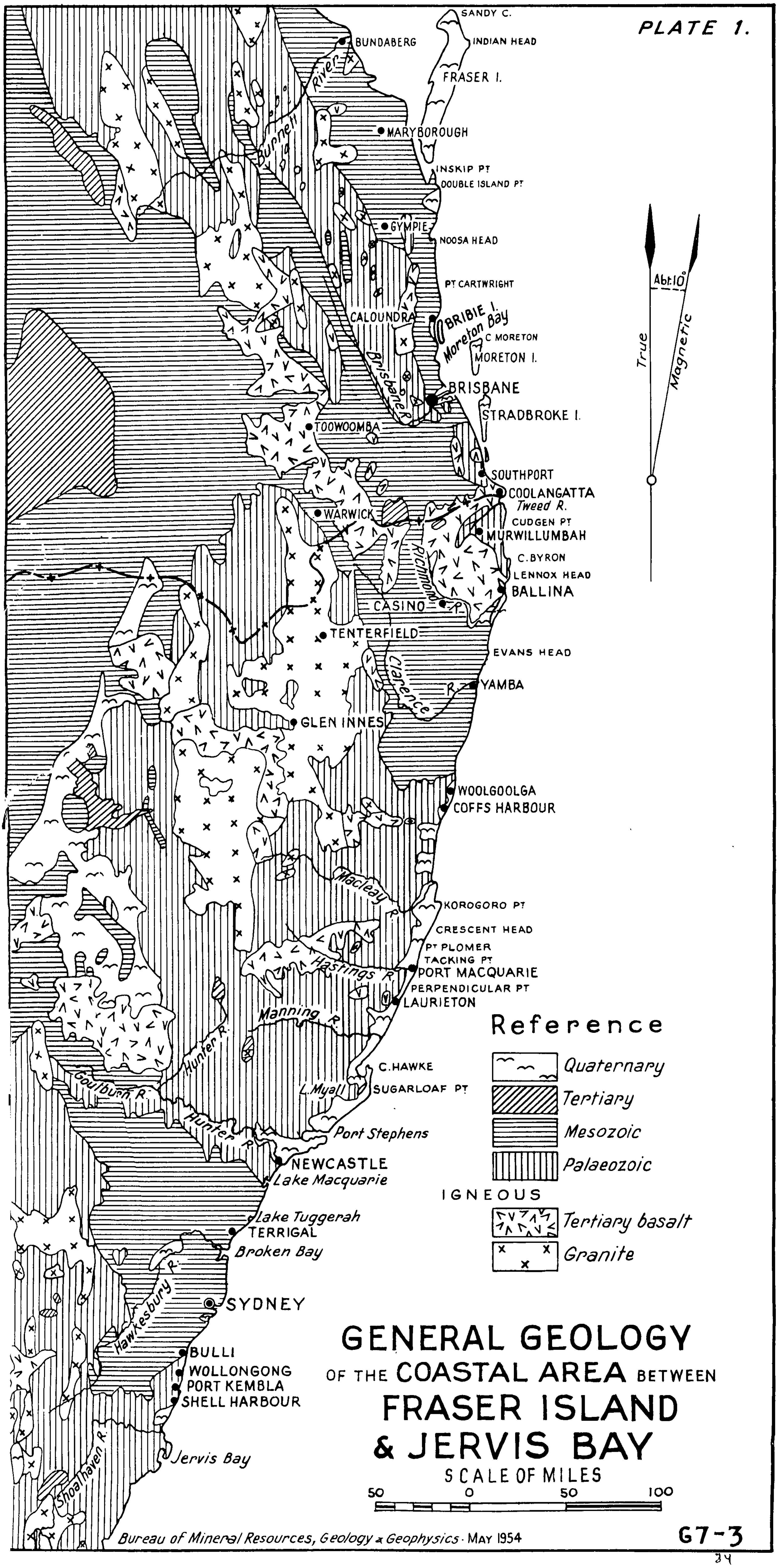
PLATE 1.
SANDY C.
INDIAN HEAD
FRASER I.
BUNDABERG
Burnett R.
MARYBOROUGH
INSKIP PT
DOUBLE ISLAND PT
GYMPIE
NOOSA HEAD
PT CARTWRIGHT
CALOUNDRA
BRIBIE I.
Moreton Bay
C MORETON
MORETON I.
Brisbane R.
BRISBANE
STRADBROKE I.
TOOWOOMBA
SOUTHPORT
COOLANGATTA
Tweed R.
CUDGEN PT
WARWICK
MURWILLUMBAH
C. BYRON
LENNOX HEAD
BALLINA
Richmond R.
CASINO
TENTERFIELD
EVANS HEAD
Clarence R.
YAMBA
GLEN INNES
WOOLGOOLGA
COFFS HARBOUR
Macleay R.
KOROGORO PT
CRESCENT HEAD
PT PLOMER
TACKING PT
PORT MACQUARIE
Hastings R.
PERPENDICULAR PT
LAURIETON
Manning R.
Hunter R.
Goulburn R.
C. HAWKE
SUGARLOAF PT
L. Myall
Port Stephens
NEWCASTLE
Lake Macquarie
Lake Tuggerah
TERRIGAL
Broken Bay
Hawkesbury R.
SYDNEY
BULLI
WOLLONGONG
PORT KEMBLA
SHELL HARBOUR
Shoalhaven R.
Jervis Bay
True
Magnetic
Abt 10°
Reference
Quaternary
Tertiary
Mesozoic
Palaeozoic
IGNEOUS
Tertiary basalt
Granite
GENERAL GEOLOGY
OF THE COASTAL AREA BETWEEN
FRASER ISLAND
& JERVIS BAY
SCALE OF MILES
50 0 50 100
Bureau of Mineral Resources, Geology & Geophysics · May 1954
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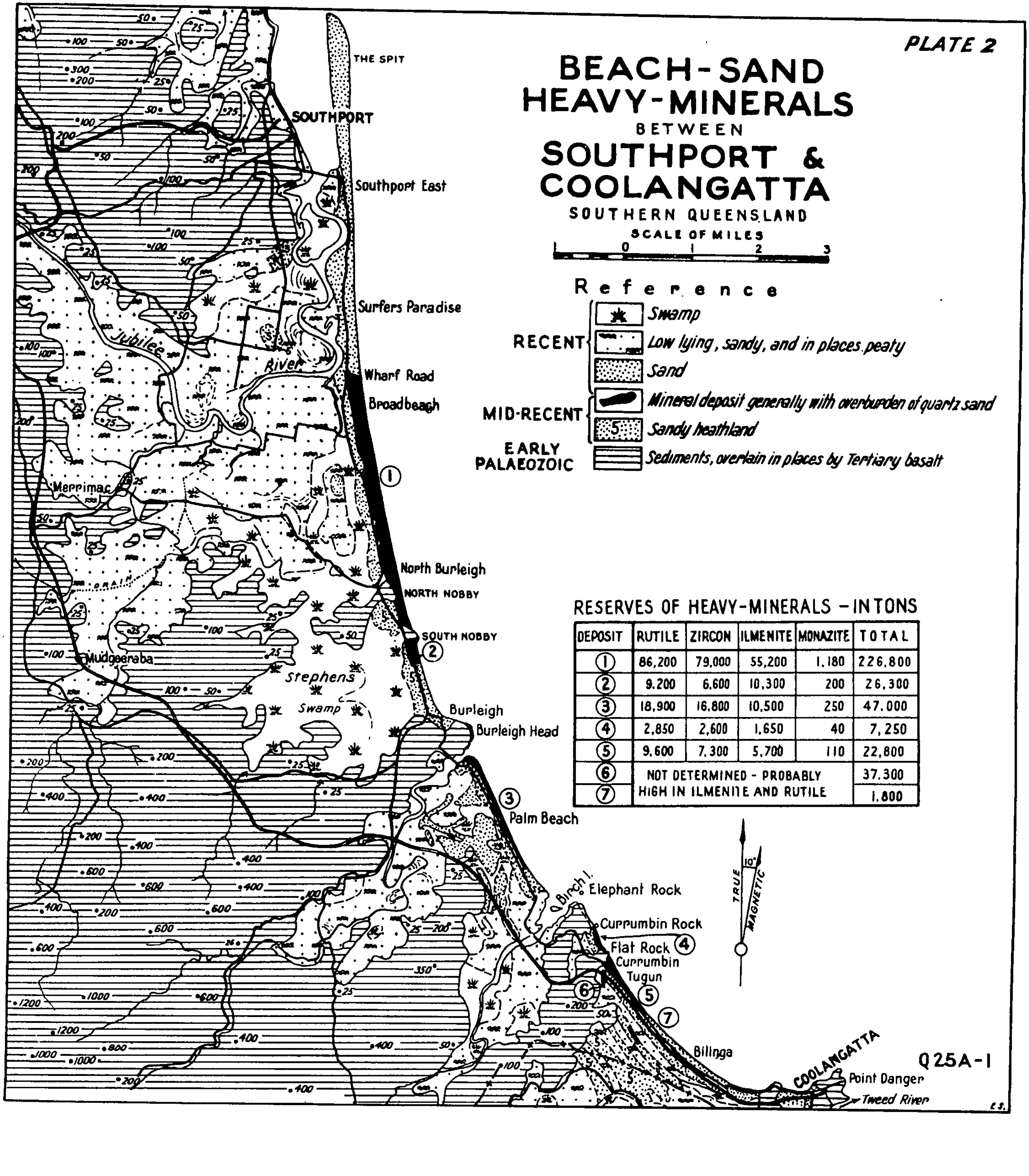
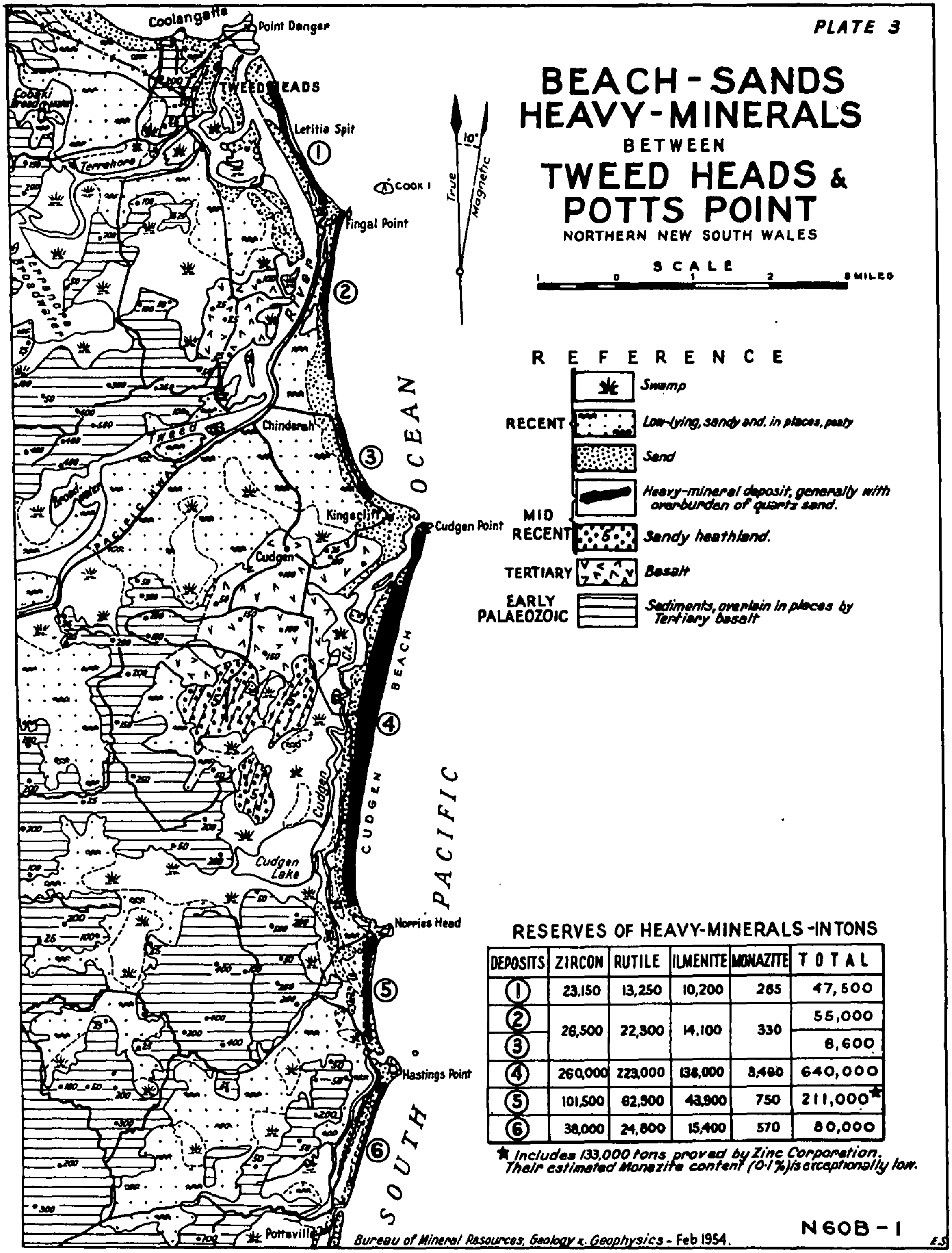


RESERVES OF HEAVY-MINERALS - IN TONS

DEPOSIT	RUTILE	ZIRCON	ILMENITE	MONAZITE	TOTAL
1	86,200	79,000	55,200	1,180	226,800
2	9,200	6,600	10,300	200	26,300
3	18,900	16,800	10,500	250	47,000
4	2,850	2,600	1,650	40	7,250
5	9,600	7,300	5,700	110	22,800
6	NOT DETERMINED - PROBABLY HIGH IN ILMENITE AND RUTILE				37,300
7					1,800



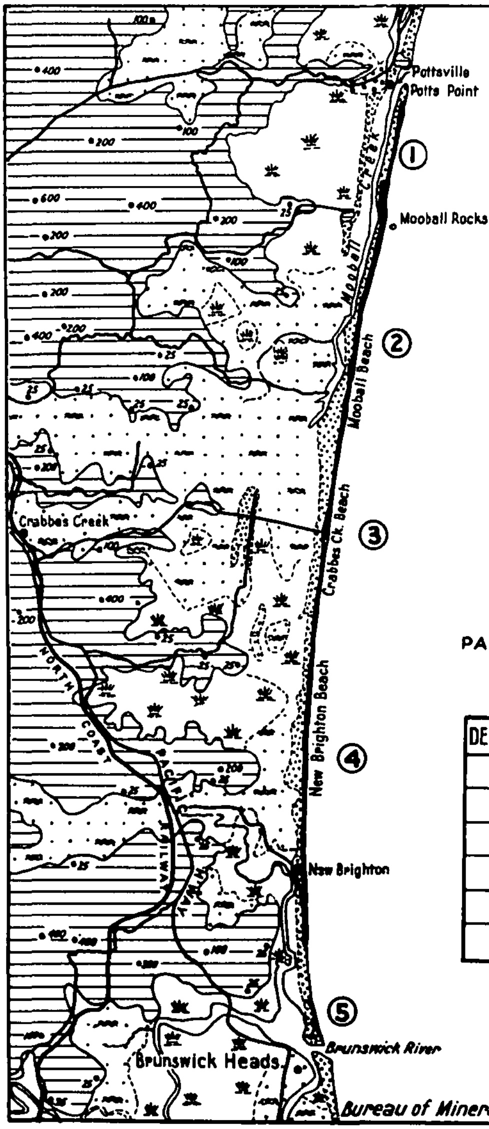
RESERVES OF HEAVY-MINERALS - IN TONS

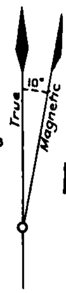
DEPOSITS	ZIRCON	RUTILE	ILMENITE	MONAZITE	TOTAL
1	23,150	13,250	10,200	265	47,500
2	26,500	22,300	14,100	330	55,000
3					8,600
4	260,000	223,000	136,000	3,460	640,000
5	101,500	62,900	43,900	750	211,000*
6	38,000	24,800	15,400	570	80,000

* Includes 133,000 tons proved by Zinc Corporation. Their estimated Monazite content (0·1%) is exceptionally low.

PLATE 4

BEACH SAND HEAVY-MINERALS
BETWEEN
POTTS POINT & BRUNSWICK HEADS
NORTHERN NEW SOUTH WALES





SCALE
1 0 1 2 3 MILES

REFERENCE

RECENT
- Swamp
- Low-lying, sandy, & in places, peaty
- Sand
- Heavy-mineral deposit, generally with overburden of quartz sand.

EARLY PALAEOZOIC
- Sediments, overlain in places by Tertiary basalt.

RESERVES OF HEAVY-MINERALS - IN TONS

DEPOSITS	WEIGHT
①	25,100
②	77,100
③	32,000
④	54,700
⑤	4,800
	193,700

MINERALS	WEIGHT
ZIRCON	81,600
RUTILE	68,200
ILMENITE	39,300
MONAZITE	1,140
OTHERS	3,500
TOTAL	193,700

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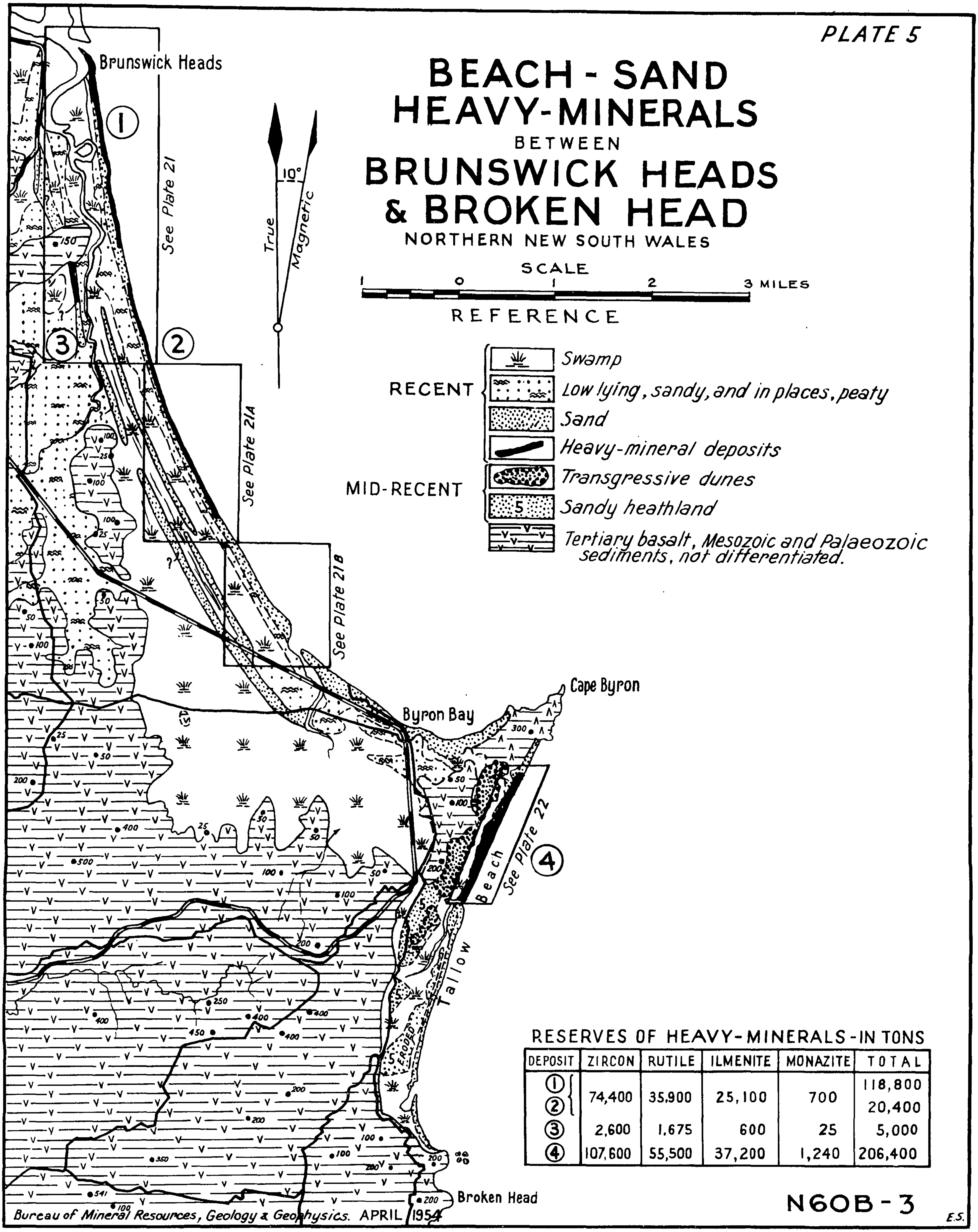
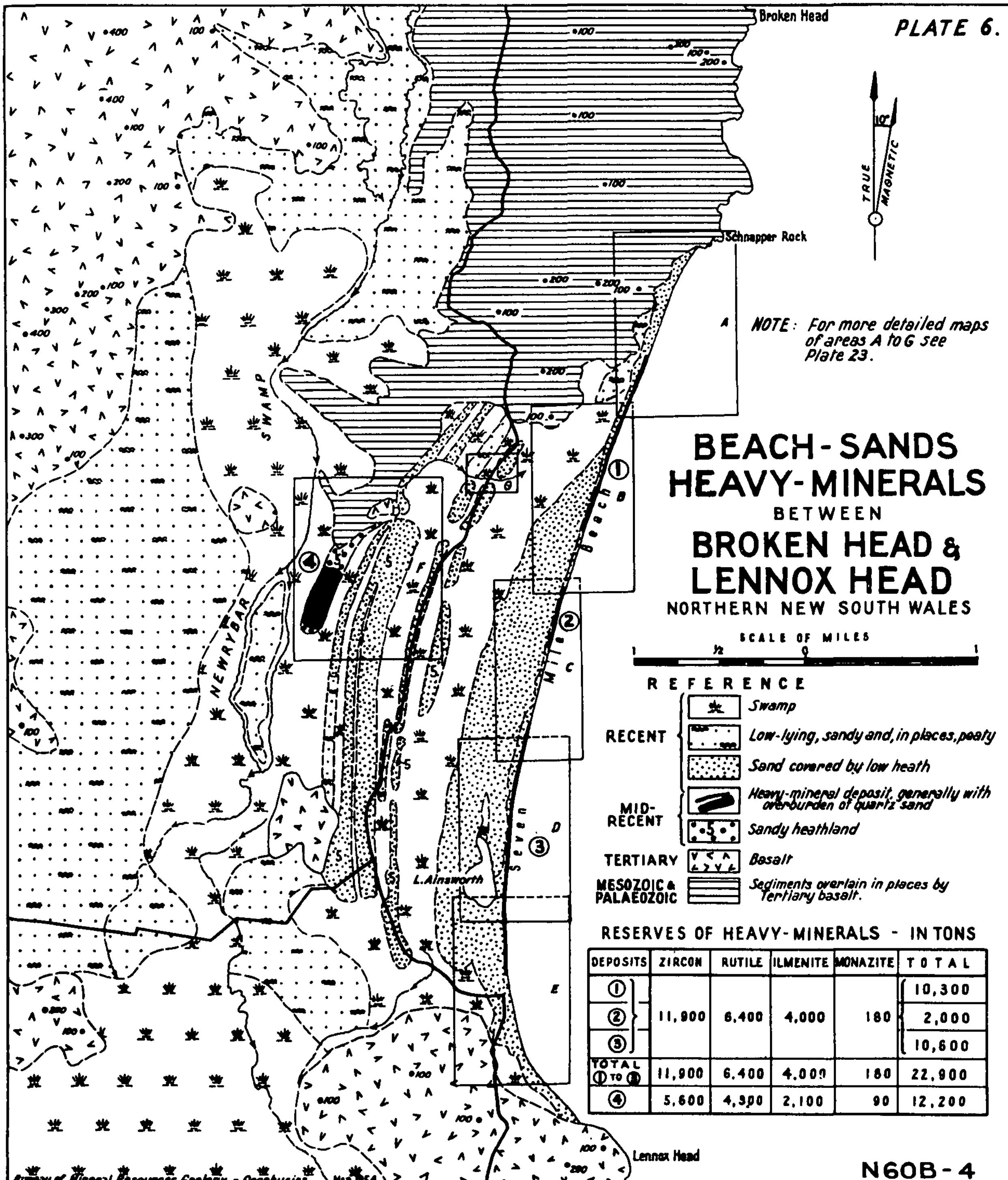
PLATE 5



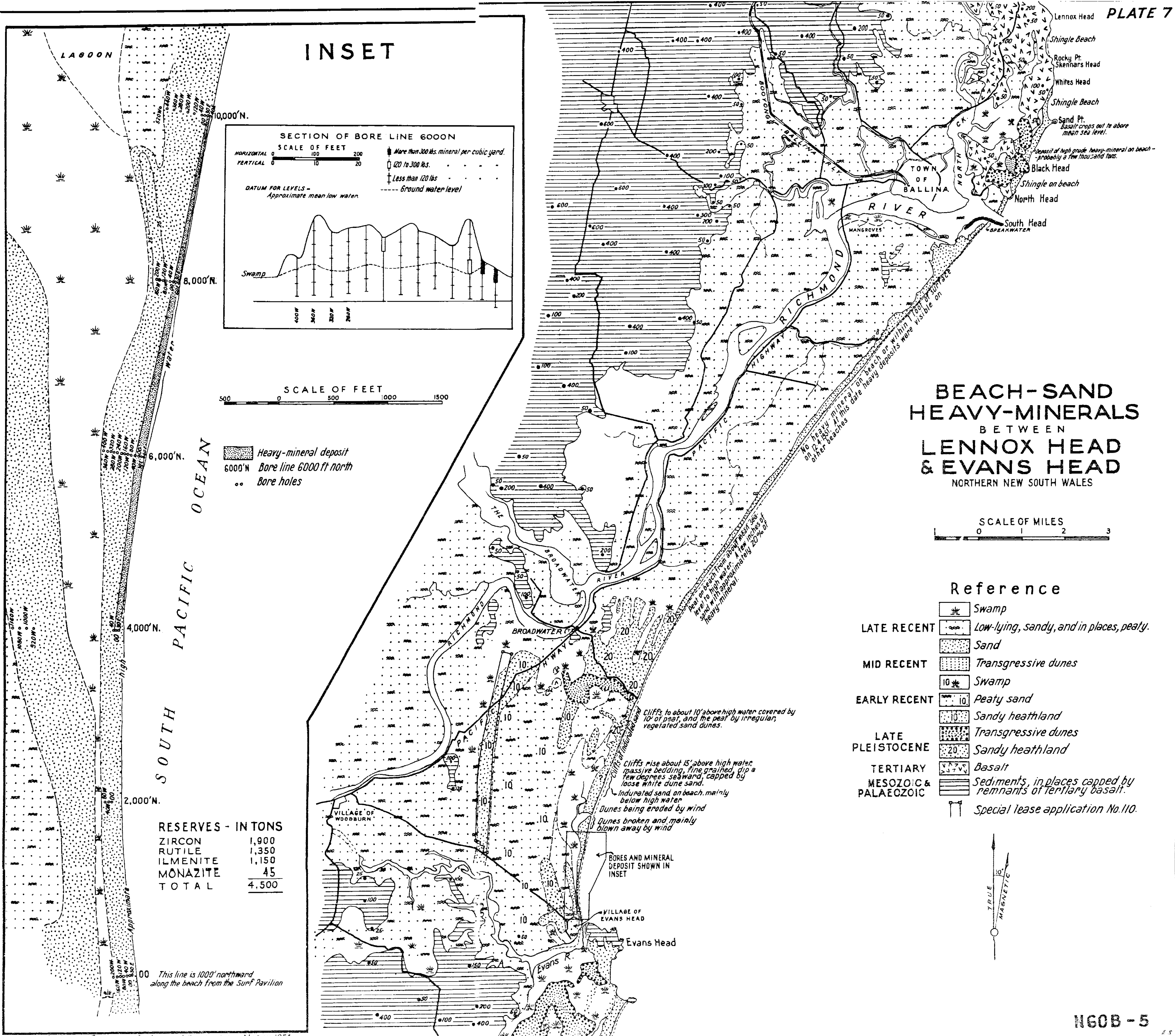
RESERVES OF HEAVY-MINERALS - IN TONS

DEPOSIT	ZIRCON	RUTILE	ILMENITE	MONAZITE	TOTAL
① ②	74,400	35,900	25,100	700	118,800 / 20,400
③	2,600	1,675	600	25	5,000
④	107,600	55,500	37,200	1,240	206,400



RESERVES OF HEAVY-MINERALS - IN TONS

DEPOSITS	ZIRCON	RUTILE	ILMENITE	MONAZITE	TOTAL
①					10,300
②	11,900	6.400	4,000	180	2,000
③					10,600
TOTAL ① TO ③	11,900	6.400	4,000	180	22,900
④	5,600	4,300	2,100	90	12,200



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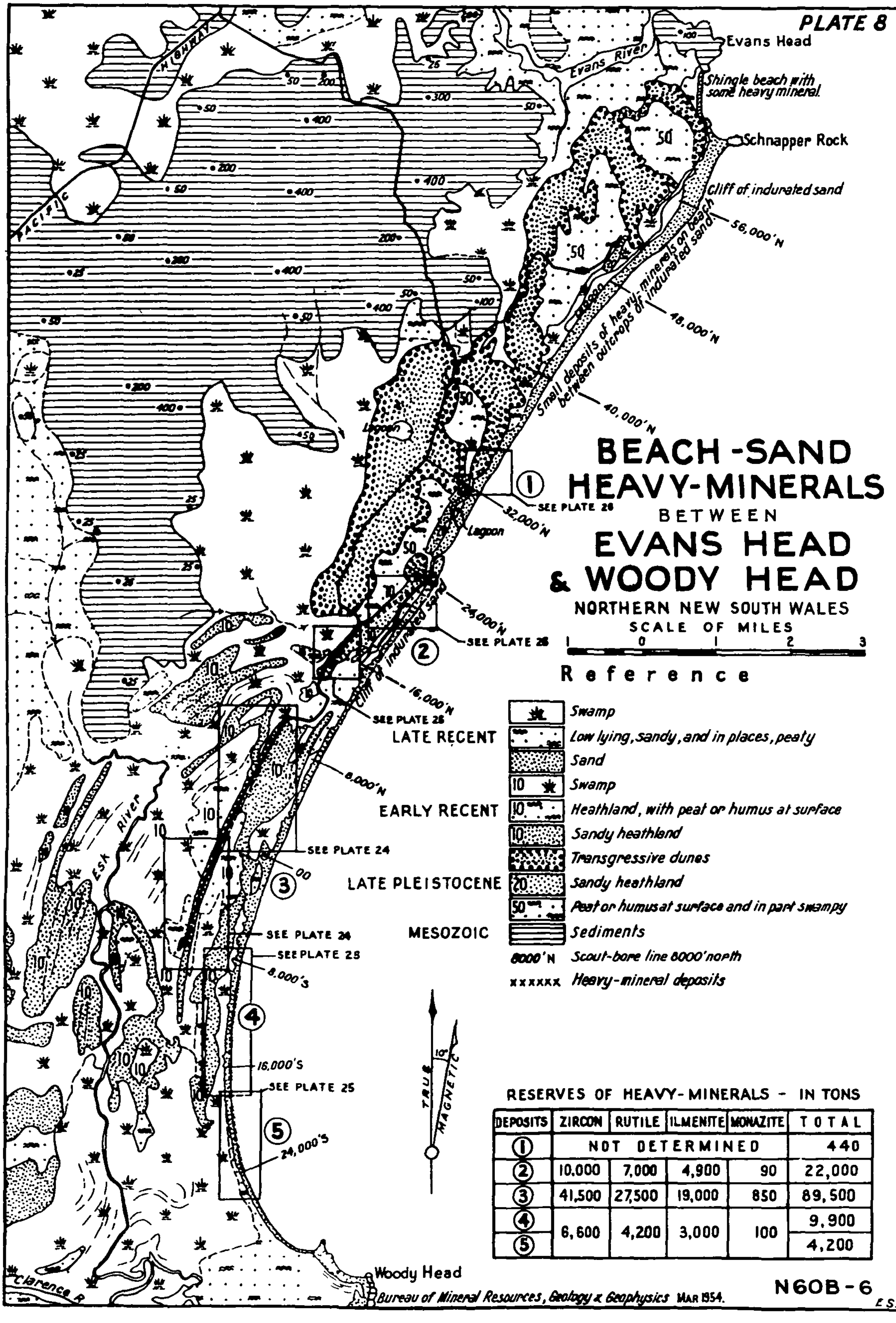

RESERVES OF HEAVY-MINERALS - IN TONS

DEPOSITS	ZIRCON	RUTILE	ILMENITE	MONAZITE	TOTAL
1	NOT DETERMINED				440
2	10,000	7,000	4,900	90	22,000
3	41,500	27,500	19,000	850	89,500
4	6,600	4,200	3,000	100	9,900
5					4,200

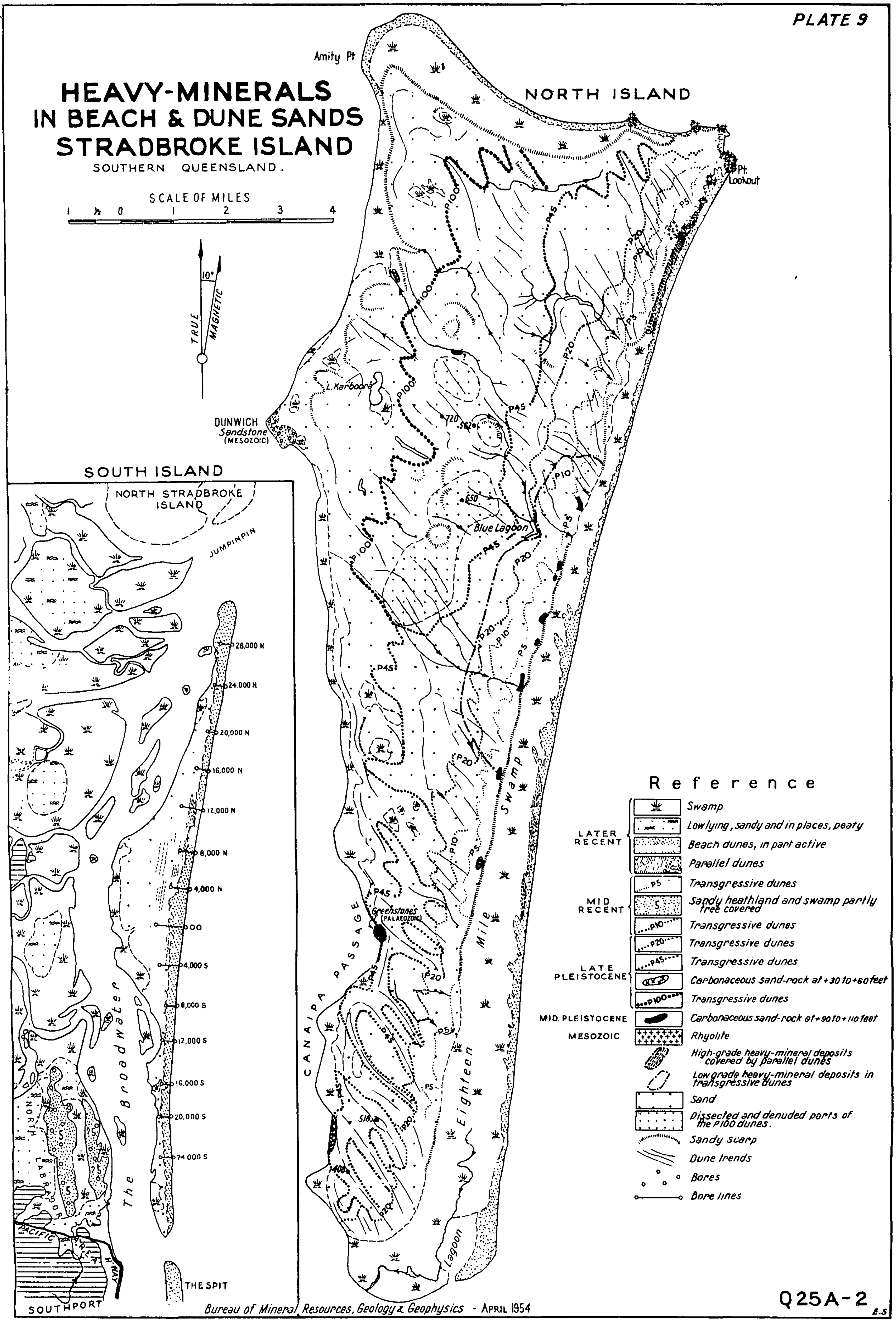
PLATE 9
HEAVY-MINERALS
IN BEACH & DUNE SANDS
STRADBROKE ISLAND
SOUTHERN QUEENSLAND.
SCALE OF MILES
1 ½ 0 1 2 3 4
10°
TRUE
MAGNETIC
Amity Pt
NORTH ISLAND
Pt. Lookout
L. Karboora
DUNWICH
Sandstone
(MESOZOIC)
Blue Lagoon
Greenstones
(PALAEOZOIC)
CANAIPA PASSAGE
Eighteen Mile Swamp
Lagoon
P100
P45
P20
P10
P5
SOUTH ISLAND
NORTH STRADBROKE ISLAND
JUMPINPIN
28,000 N
24,000 N
20,000 N
16,000 N
12,000 N
8,000 N
4,000 N
00
4,000 S
8,000 S
12,000 S
16,000 S
20,000 S
24,000 S
The Broadwater
NORTH LABRADOR
PACIFIC HIGHWAY
THE SPIT
SOUTHPORT
Reference
Swamp
Low lying, sandy and in places, peaty
LATER RECENT
Beach dunes, in part active
Parallel dunes
Transgressive dunes
MID RECENT
Sandy heathland and swamp partly tree covered
Transgressive dunes
Transgressive dunes
LATE PLEISTOCENE
Transgressive dunes
Carbonaceous sand-rock at +30 to +60 feet
Transgressive dunes
MID. PLEISTOCENE
Carbonaceous sand-rock at +90 to +110 feet
MESOZOIC
Rhyolite
High-grade heavy-mineral deposits covered by parallel dunes
Low grade heavy-mineral deposits in transgressive dunes
Sand
Dissected and denuded parts of the P100 dunes.
Sandy scarp
Dune trends
Bores
Bore lines
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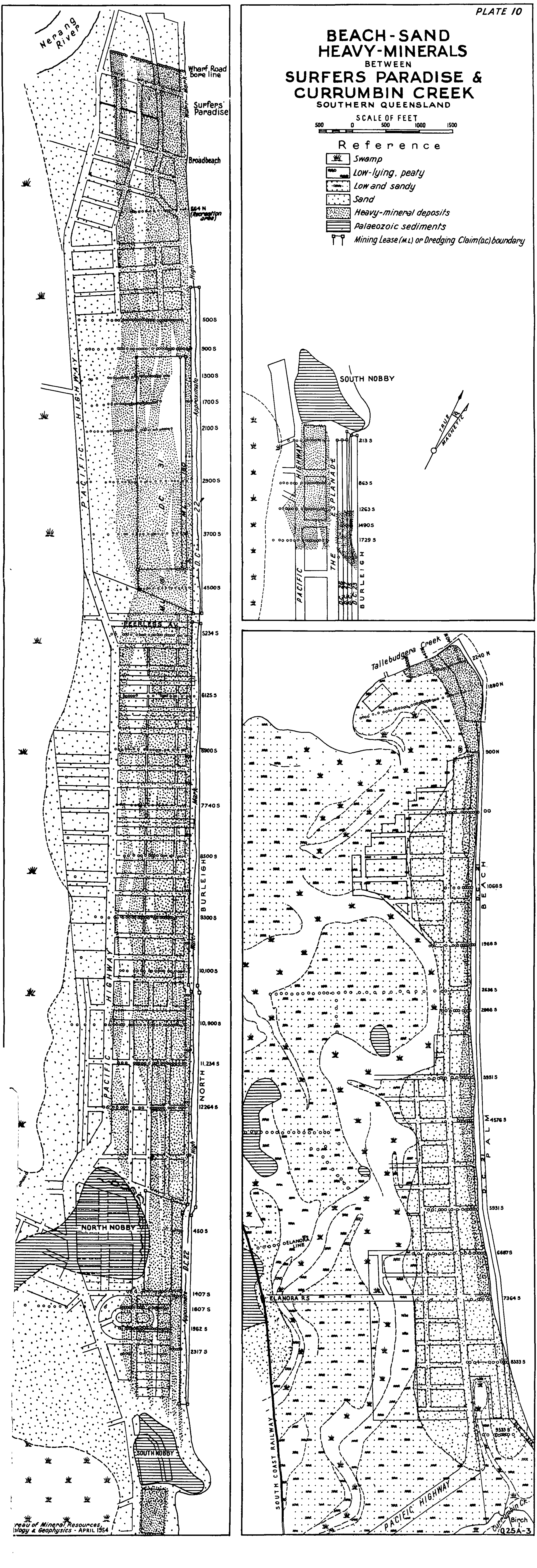
PLATE 10
BEACH-SAND HEAVY-MINERALS
BETWEEN
SURFERS PARADISE & CURRUMBIN CREEK
SOUTHERN QUEENSLAND
SCALE OF FEET
500 0 500 1000 1500
Reference
Swamp
Low-lying, peaty
Low and sandy
Sand
Heavy-mineral deposits
Palaeozoic sediments
Mining Lease (M.L.) or Dredging Claim (D.C.) boundary
Nerang River
Wharf Road bore line
Surfers' Paradise
Broadbeach
PACIFIC HIGHWAY
D.C. 3
D.C. 22
PEERLESS
NORTH BURLEIGH
NORTH NOBBY
SOUTH NOBBY
THE ESPLANADE
BURLEIGH
TRUE
MAGNETIC
Tallebudgera Creek
PALM BEACH
ELANORA R.S.
SOUTH COAST RAILWAY
Currumbin Ck.
Birch
Bureau of Mineral Resources Geology & Geophysics - APRIL 1954
Q25A-3

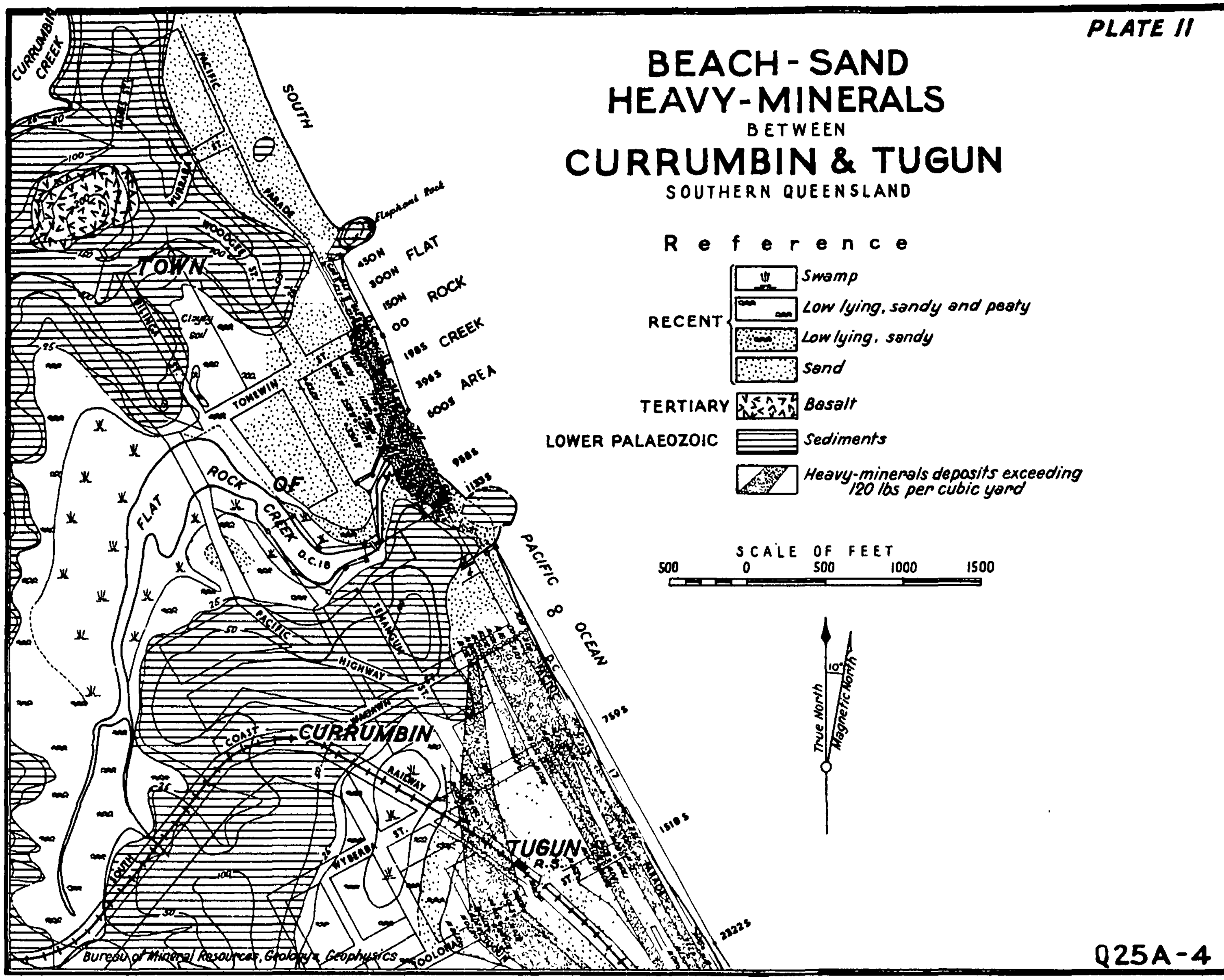

PLATE II
BEACH - SAND
HEAVY - MINERALS
BETWEEN
CURRUMBIN & TUGUN
SOUTHERN QUEENSLAND
Reference
RECENT
Swamp
Low lying, sandy and peaty
Low lying, sandy
Sand
TERTIARY
Basalt
LOWER PALAEOZOIC
Sediments
Heavy-minerals deposits exceeding 120 lbs per cubic yard
SCALE OF FEET
500 0 500 1000 1500
True North
Magnetic North
10°
CURRUMBIN CREEK
TOWN
FLAT ROCK CREEK
OF
FLAT ROCK CREEK AREA
CURRUMBIN
TUGUN
SOUTH PACIFIC OCEAN
PACIFIC HIGHWAY
COAST RAILWAY
Elephant Rock
Bureau of Mineral Resources, Geology & Geophysics
Q25A-4

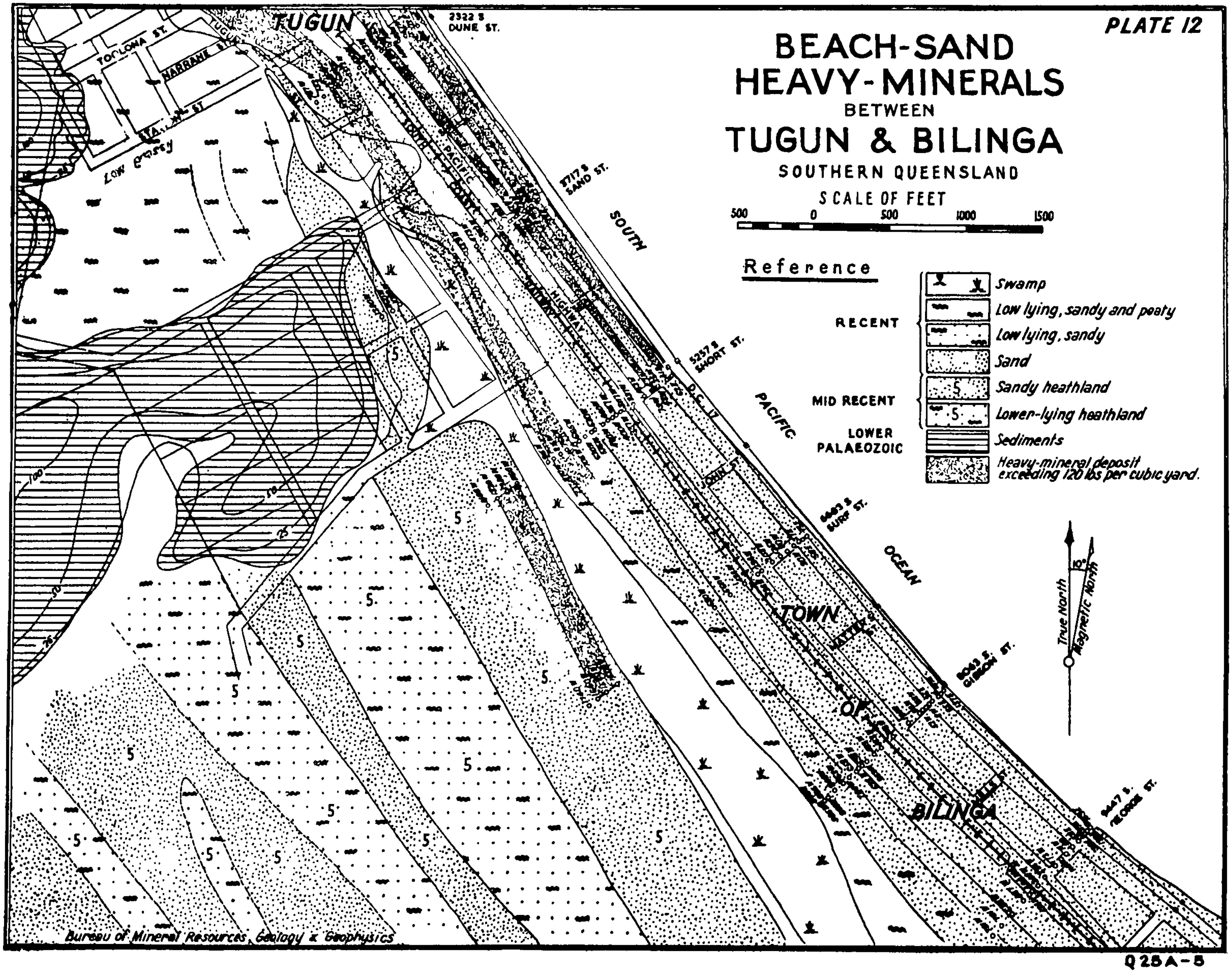
PLATE 12
BEACH-SAND
HEAVY-MINERALS
BETWEEN
TUGUN & BILINGA
SOUTHERN QUEENSLAND
SCALE OF FEET
500 0 500 1000 1500
Reference
RECENT
Swamp
Low lying, sandy and peaty
Low lying, sandy
Sand
MID RECENT
Sandy heathland
Lower-lying heathland
LOWER PALAEOZOIC
Sediments
Heavy-mineral deposit exceeding 120 lbs per cubic yard.
True North
Magnetic North
10°
TUGUN
2322 S DUNE ST.
2717 S SAND ST.
5257 S SHORT ST.
SURF ST.
GIBSON ST.
GEORGE ST.
SOUTH PACIFIC OCEAN
TOWN OF BILINGA
HIGHWAY
Low grassy
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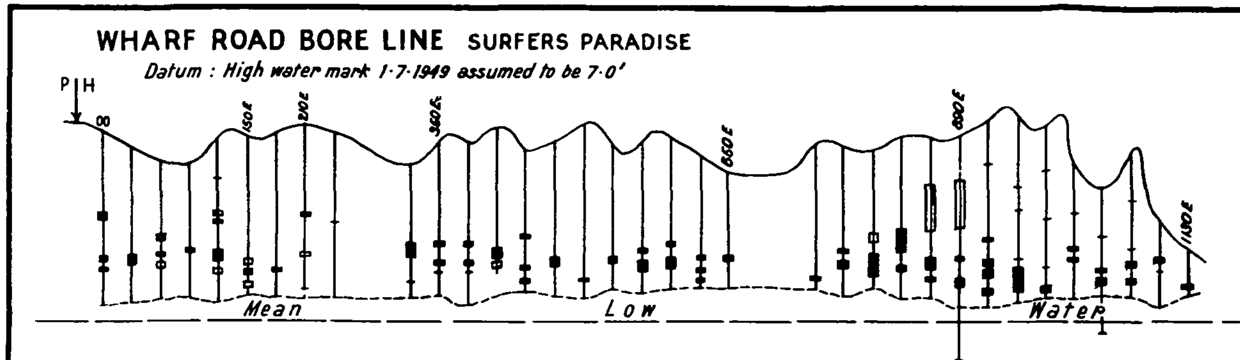
Q25A-5

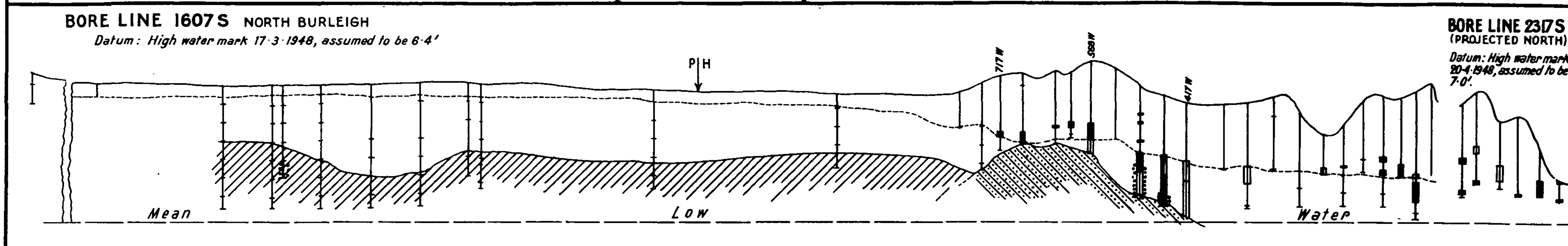
PLATE 13

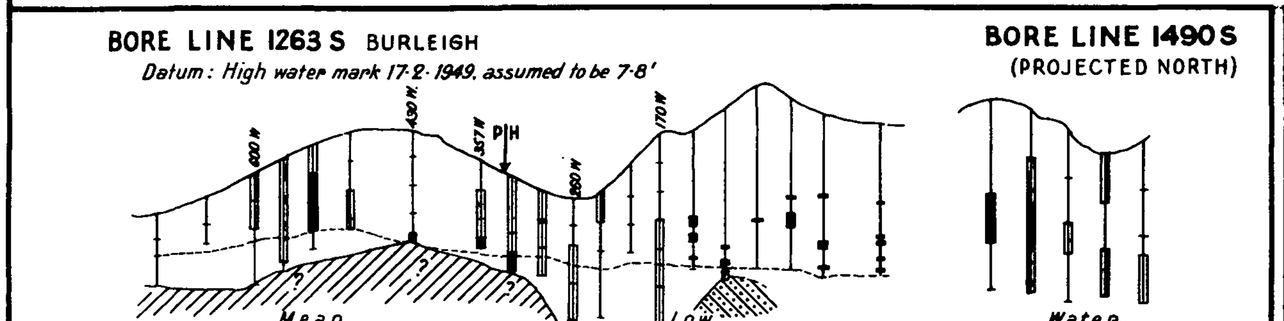
BEACH - SAND HEAVY-MINERALS BETWEEN SOUTHPORT AND COOLANGATTA.

SOUTHERN QUEENSLAND

SECTIONS ALONG TYPICAL BORE LINES



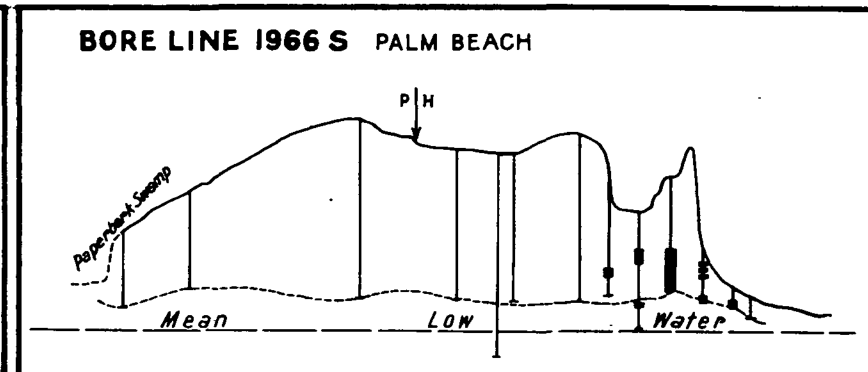


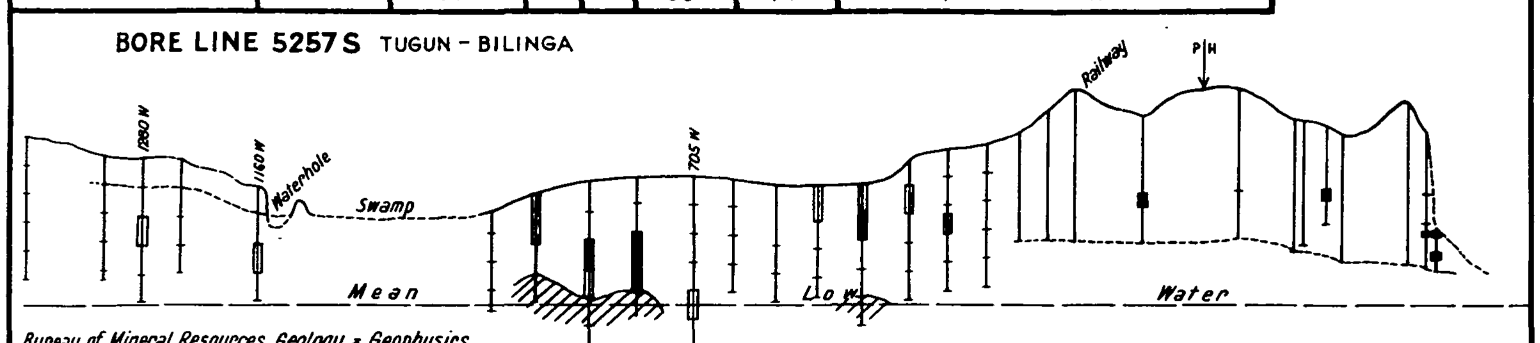


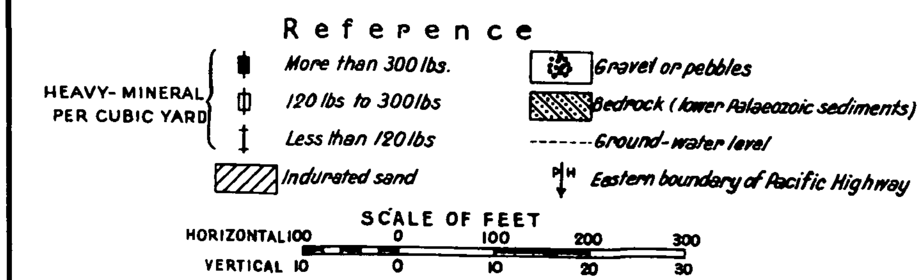
Percentage composition (approximate) to water-level						
ZIRCON	26	36	29	44	40	41
RUTILE	18	22	19	27	29	30
ILMENITE	54	41	52	27	30✱	26
MONAZITE	0	0·1	0·1	0·8	0·5	1·4

The compositions given are those of composite samples from four (4) bore lines.

✱ Ilmenite high because samples included from +5 foot deposits in line 213 S.







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Q25A-6

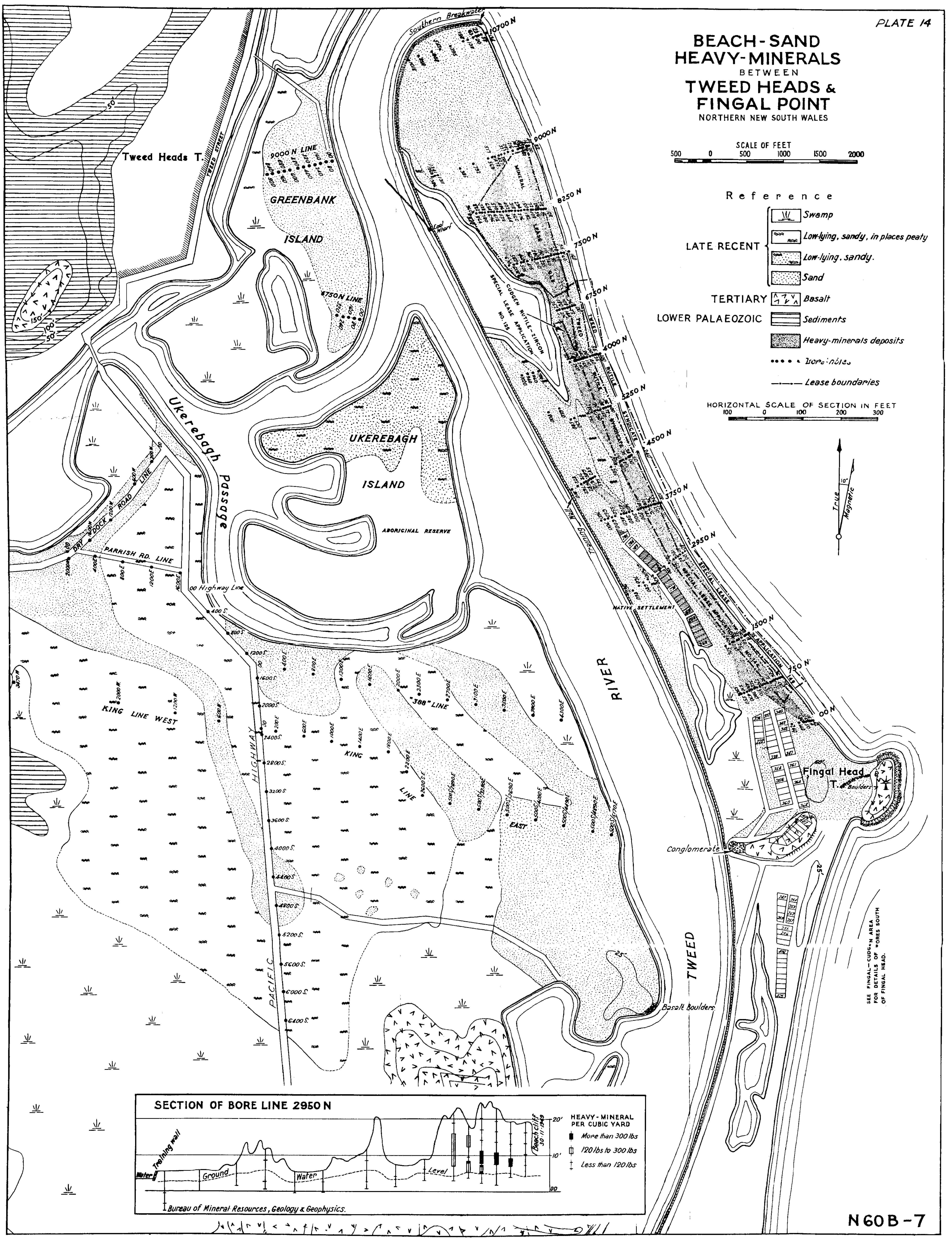
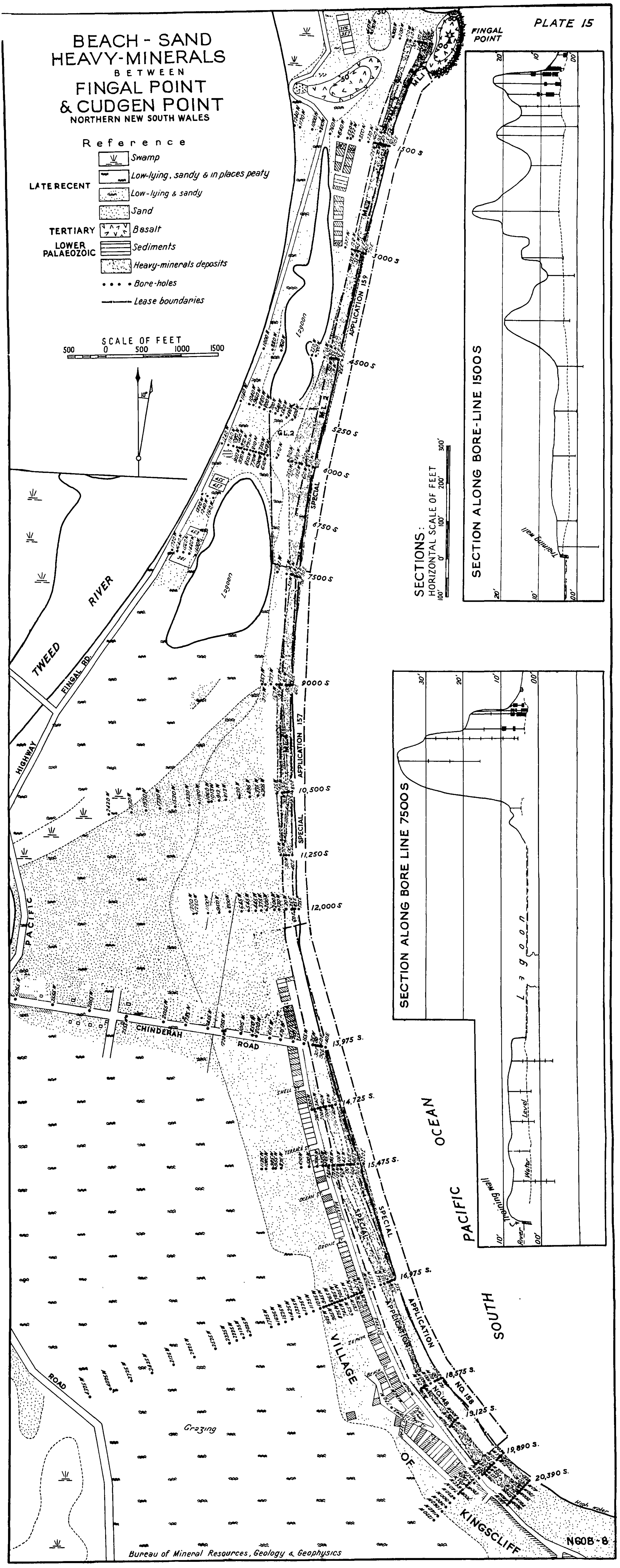


PLATE 14
BEACH-SAND HEAVY-MINERALS BETWEEN TWEED HEADS & FINGAL POINT
NORTHERN NEW SOUTH WALES
SCALE OF FEET
500 0 500 1000 1500 2000
Reference
LATE RECENT
Swamp
Low-lying, sandy, in places peaty
Low-lying, sandy.
Sand
TERTIARY
Basalt
LOWER PALAEOZOIC
Sediments
Heavy-minerals deposits
Lease boundaries
HORIZONTAL SCALE OF SECTION IN FEET
100 0 100 200 300
True
Magnetic
Tweed Heads T.
TWEED STREET
GREENBANK ISLAND
9000 N LINE
6750 N LINE
Ukerebagh Passage
UKEREBAGH ISLAND
ABORIGINAL RESERVE
DRY DOCK ROAD LINE
PARRISH RD. LINE
00 Highway Line
KING LINE WEST
PACIFIC HIGHWAY
KING LINE
"388" LINE
EAST
Southern Breakwater
Coal Wharf
SPECIAL LEASE APPLICATION NO. 125
CUDGEN RUTILE-ZIRCON
MINERAL LEASE
TWEED RUTILE SYNDICATE
SPECIAL LEASE APPLICATION
NATIVE SETTLEMENT
Terranora Rd
RIVER
TWEED
Fingal Head T.
Boulders
Conglomerate
Basalt Boulders
10700 N
9000 N
8250 N
7500 N
6750 N
6000 N
5250 N
4500 N
3750 N
2950 N
1500 N
750 N
00 N
SEE FINGAL-CUDGEN AREA FOR DETAILS OF BORES SOUTH OF FINGAL HEAD.
SECTION OF BORE LINE 2950 N
Training wall
Water
Ground
Water
Level
Beach cliff 30-11-1949
20'
10'
00
HEAVY-MINERAL PER CUBIC YARD
More than 300 lbs
120 lbs to 300 lbs
Less than 120 lbs
Bureau of Mineral Resources, Geology & Geophysics.
N60B-7


BEACH - SAND
HEAVY-MINERALS
BETWEEN
FINGAL POINT
& CUDGEN POINT
NORTHERN NEW SOUTH WALES
Reference
Swamp
Low-lying, sandy & in places peaty
LATE RECENT
Low-lying & sandy
Sand
TERTIARY
Basalt
LOWER PALAEOZOIC
Sediments
Heavy-minerals deposits
Bore-holes
Lease boundaries
SCALE OF FEET
500 0 500 1000 1500
FINGAL POINT
Lagoon
APPLICATION 159
M.L.1
M.L.2
SPECIAL
Lagoon
TWEED
RIVER
FINGAL RD.
HIGHWAY
PACIFIC
APPLICATION 157
SPECIAL
CHINDERAH
ROAD
SPECIAL
APPLICATION
SPECIAL
APPLICATION
VILLAGE
OF
KINGSCLIFF
No. 158
No. 148
ROAD
Grazing
SOUTH
PACIFIC
OCEAN
High water
1500 S
3000 S
4500 S
5250 S
6000 S
6750 S
7500 S
9000 S
10,500 S
11,250 S
12,000 S
13,975 S.
14,725 S.
15,475 S.
16,975 S.
18,575 S.
19,125 S.
19,890 S.
20,390 S.
SECTIONS:
HORIZONTAL SCALE OF FEET
100' 0 100' 200' 300'
SECTION ALONG BORE-LINE 1500S
Training wall
SECTION ALONG BORE LINE 7500S
Lagoon
Training wall
River
Water
Level
N60B-8
Bureau of Mineral Resources, Geology & Geophysics

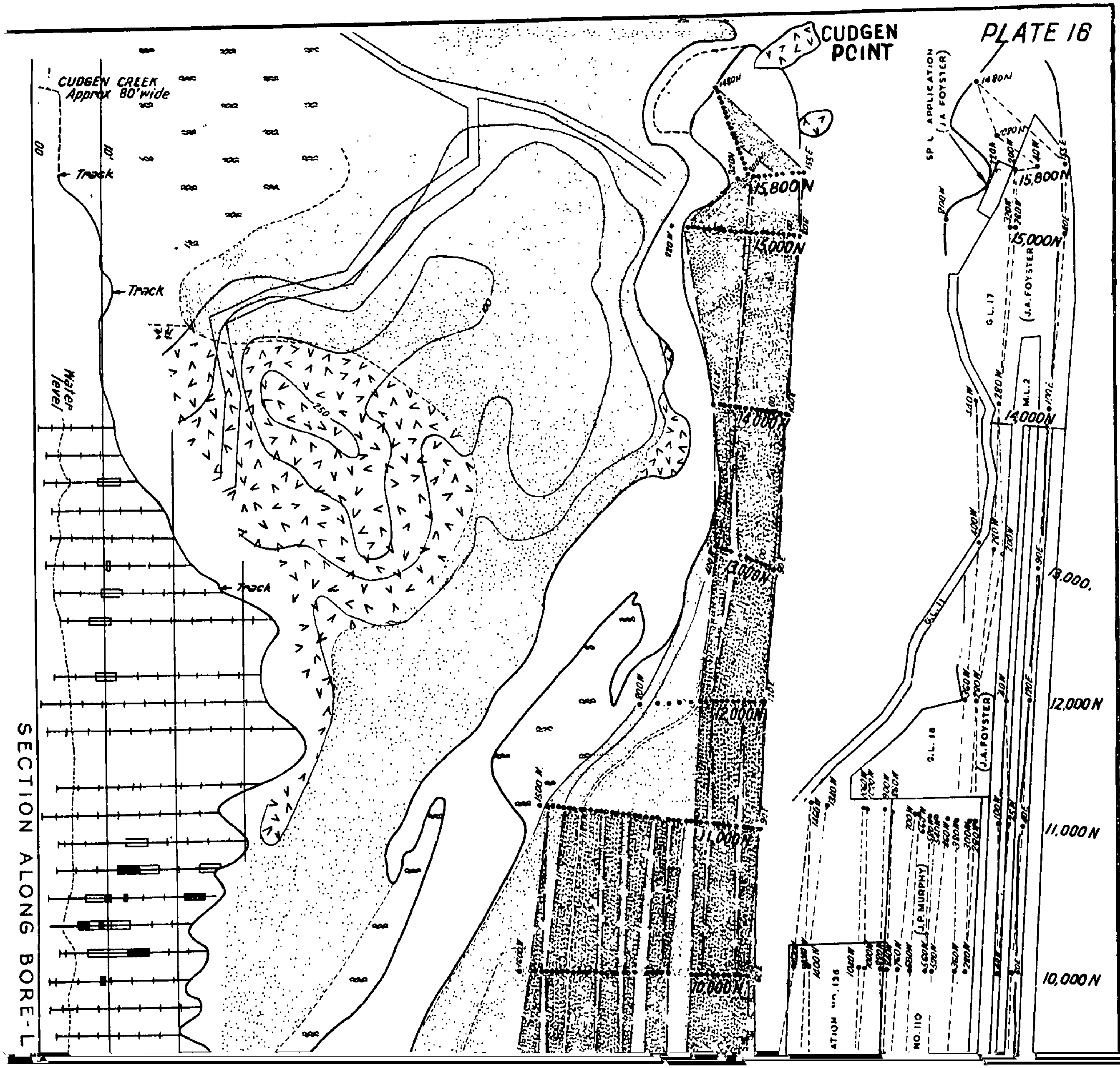
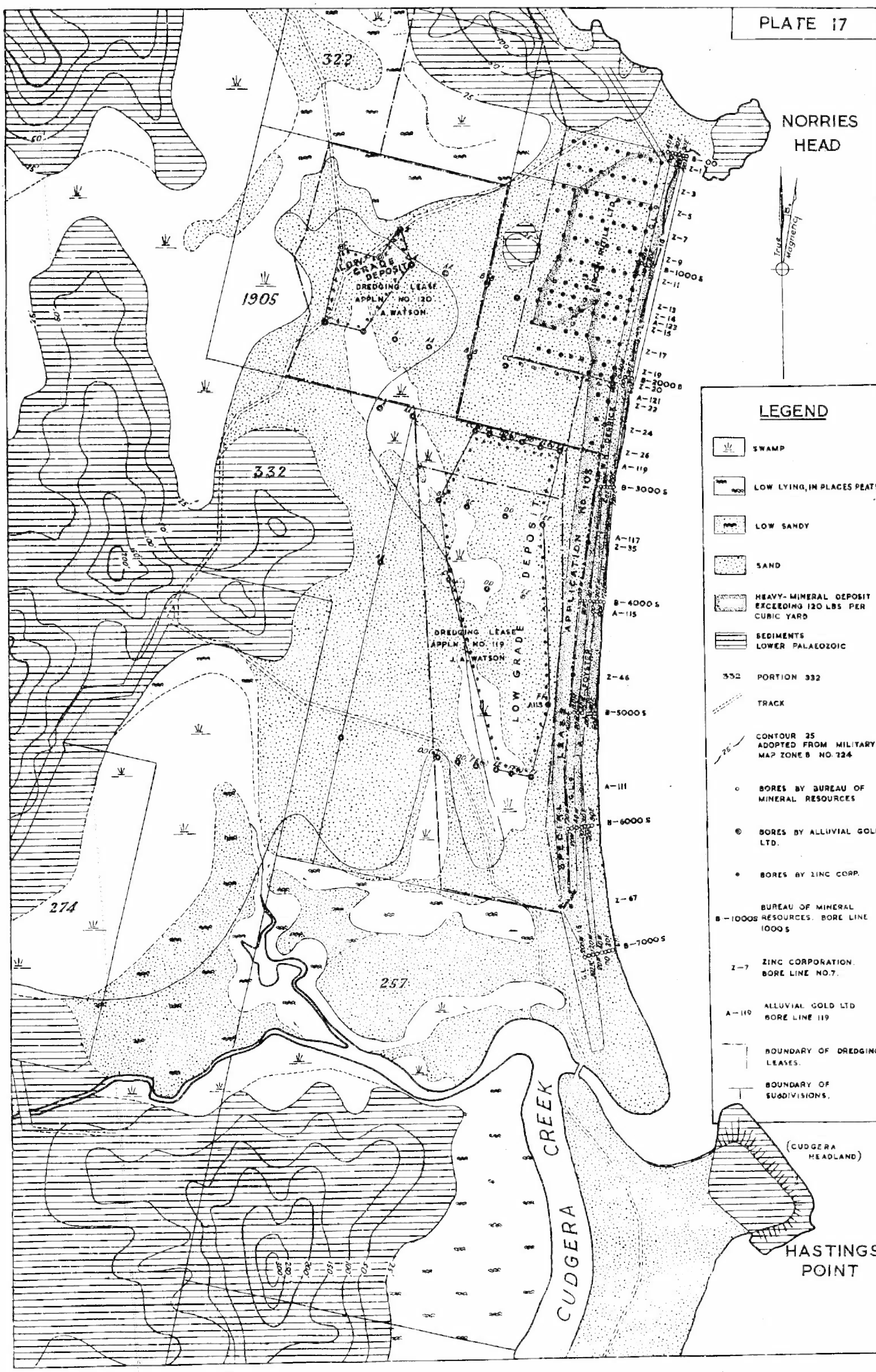


PLATE 16
CUDGEN POINT
CUDGEN CREEK
Approx 80' wide
Track
Track
Track
Water level
SECTION ALONG BORE-L
15,800N
15,000N
14,000N
13,000N
12,000N
11,000N
10,000N
SP L APPLICATION (J.A FOYSTER)
15,800N
15,000N
G.L.17
(J.A. FOYSTER)
M.L.2
14,000N
13,000.
G.L.11
G.L.18
J.A. FOYSTER
12,000N
11,000N
J.P. MURPHY
10,000N
NO.110



HEAVY-MINERAL DEPOSITS BETWEEN

NORRIES HEAD & HASTINGS POINT

NORTHERN NEW SOUTH WALES

SCALE

FEET 500 0 500 1000 1500 2000 FEET

Bureau of Mineral Resources, Geology & Geophysics

N60B-10

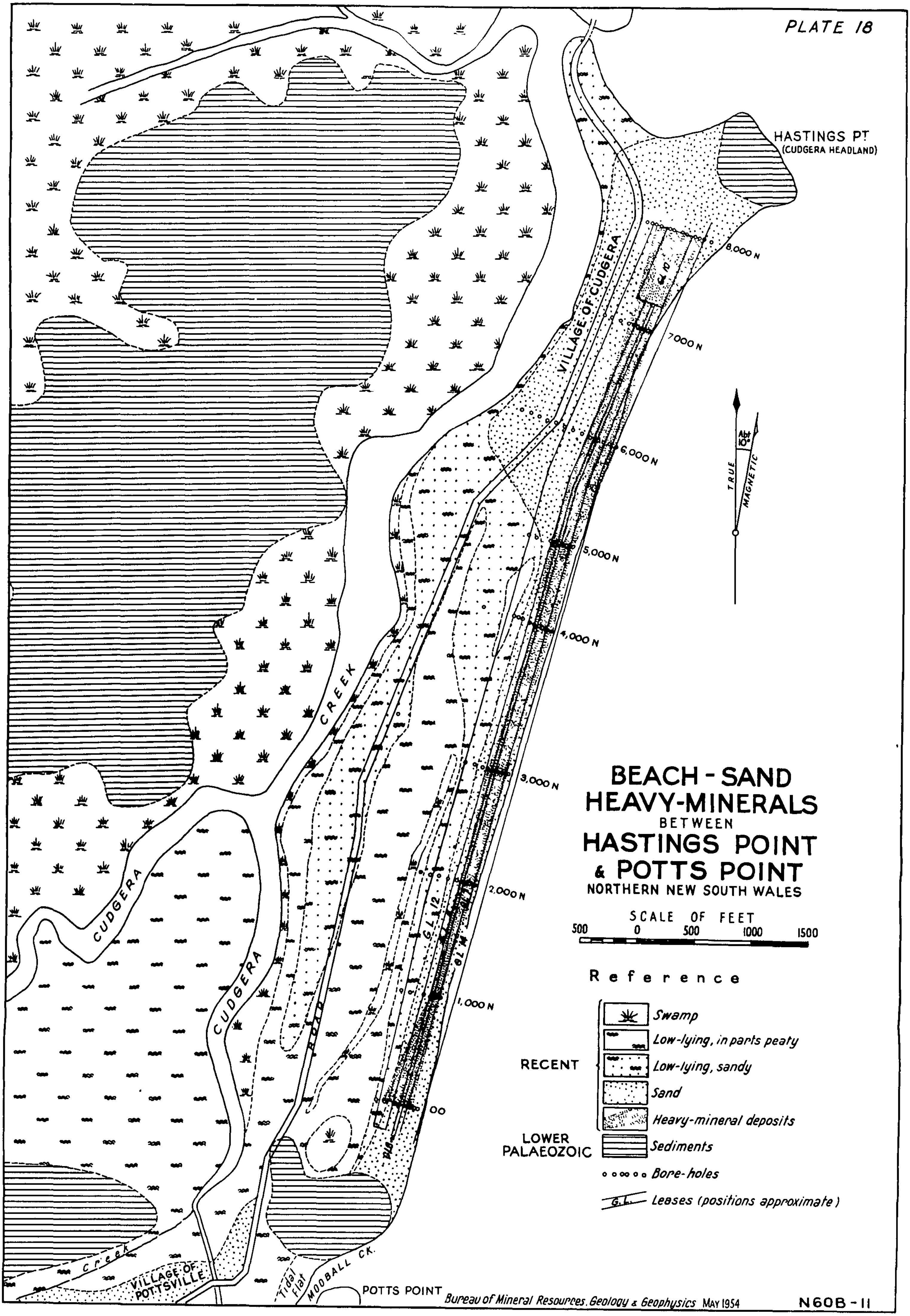


PLATE 18
HASTINGS PT
(CUDGERA HEADLAND)
VILLAGE OF CUDGERA
8,000 N
7,000 N
6,000 N
5,000 N
4,000 N
3,000 N
2,000 N
1,000 N
00
G.L. 10
G.L. 12
M.L. 18
P.L. 18
TRUE
MAGNETIC
Abt 10°
CREEK
CUDGERA
CUDGERA
ROAD
Creek
VILLAGE OF POTTSVILLE
Tidal Flat
MOOBALL CK.
POTTS POINT
BEACH - SAND
HEAVY-MINERALS
BETWEEN
HASTINGS POINT
& POTTS POINT
NORTHERN NEW SOUTH WALES
SCALE OF FEET
500 0 500 1000 1500
Reference
RECENT
Swamp
Low-lying, in parts peaty
Low-lying, sandy
Sand
Heavy-mineral deposits
LOWER PALAEOZOIC
Sediments
Bore-holes
G.L.
Leases (positions approximate)
Bureau of Mineral Resources, Geology & Geophysics MAY 1954
N60B-11

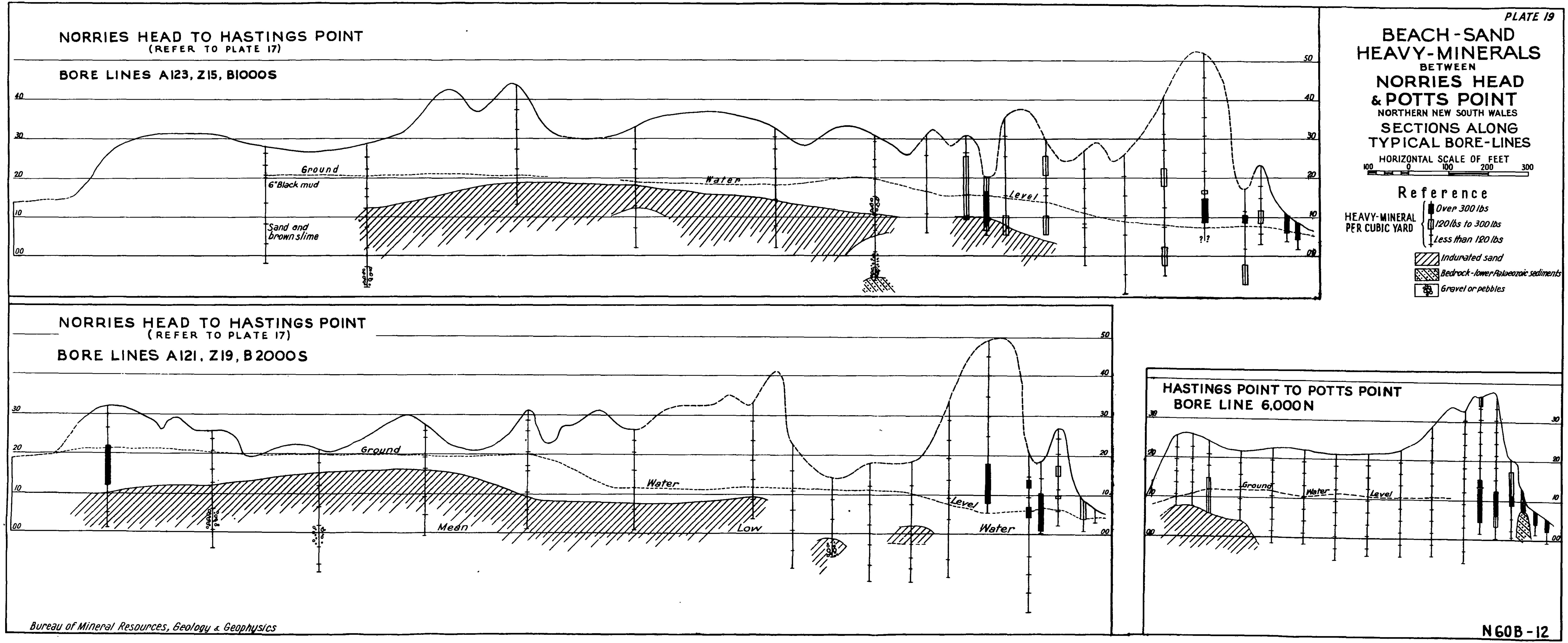


PLATE 19
BEACH-SAND
HEAVY-MINERALS
BETWEEN
NORRIES HEAD
& POTTS POINT
NORTHERN NEW SOUTH WALES
SECTIONS ALONG
TYPICAL BORE-LINES
HORIZONTAL SCALE OF FEET
100 0 100 200 300
Reference
HEAVY-MINERAL PER CUBIC YARD
Over 300 lbs
120lbs to 300lbs
Less than 120 lbs
Indurated sand
Bedrock-lower Palaeozoic sediments
Gravel or pebbles
NORRIES HEAD TO HASTINGS POINT
(REFER TO PLATE 17)
BORE LINES A123, Z15, B1000S
Ground
Water
Level
6" Black mud
Sand and brown slime
NORRIES HEAD TO HASTINGS POINT
(REFER TO PLATE 17)
BORE LINES A121, Z19, B2000S
Ground
Water
Level
Mean
Low
Water
HASTINGS POINT TO POTTS POINT
BORE LINE 6,000N
Ground
Water
Level
Bureau of Mineral Resources, Geology & Geophysics
N60B-12

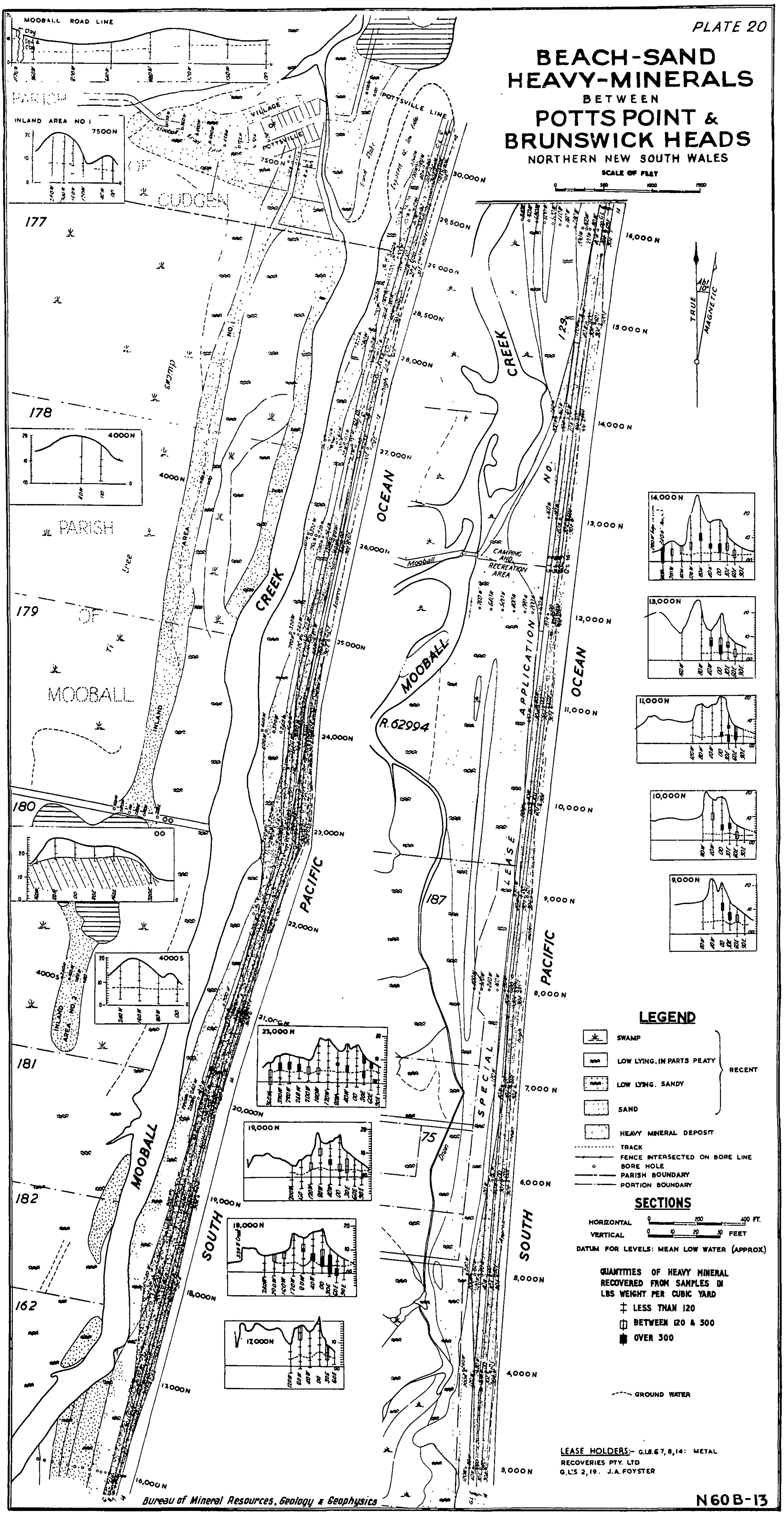


PLATE 20
BEACH-SAND HEAVY-MINERALS BETWEEN POTTS POINT & BRUNSWICK HEADS
NORTHERN NEW SOUTH WALES
SCALE OF FEET
MOOBALL ROAD LINE
INLAND AREA NO I
VILLAGE OF POTTSVILLE
POTTSVILLE LINE
PARISH OF CUDGEN
PARISH OF MOOBALL
MOOBALL CREEK
SOUTH PACIFIC OCEAN
SPECIAL LEASE APPLICATION NO. 129
CAMPING AND RECREATION AREA
R.62994
INLAND AREA NO 2
TRUE
MAGNETIC
LEGEND
SWAMP
LOW LYING, IN PARTS PEATY
LOW LYING, SANDY
SAND
RECENT
HEAVY MINERAL DEPOSIT
TRACK
FENCE INTERSECTED ON BORE LINE
BORE HOLE
PARISH BOUNDARY
PORTION BOUNDARY
SECTIONS
HORIZONTAL
VERTICAL
FEET
DATUM FOR LEVELS: MEAN LOW WATER (APPROX)
QUANTITIES OF HEAVY MINERAL RECOVERED FROM SAMPLES IN LBS WEIGHT PER CUBIC YARD
LESS THAN 120
BETWEEN 120 & 300
OVER 300
GROUND WATER
LEASE HOLDERS:- G.L.S 6 7, 8, 14: METAL RECOVERIES PTY. LTD
G.L'S 2, 19. J.A. FOYSTER
Bureau of Mineral Resources, Geology & Geophysics
N60B-13

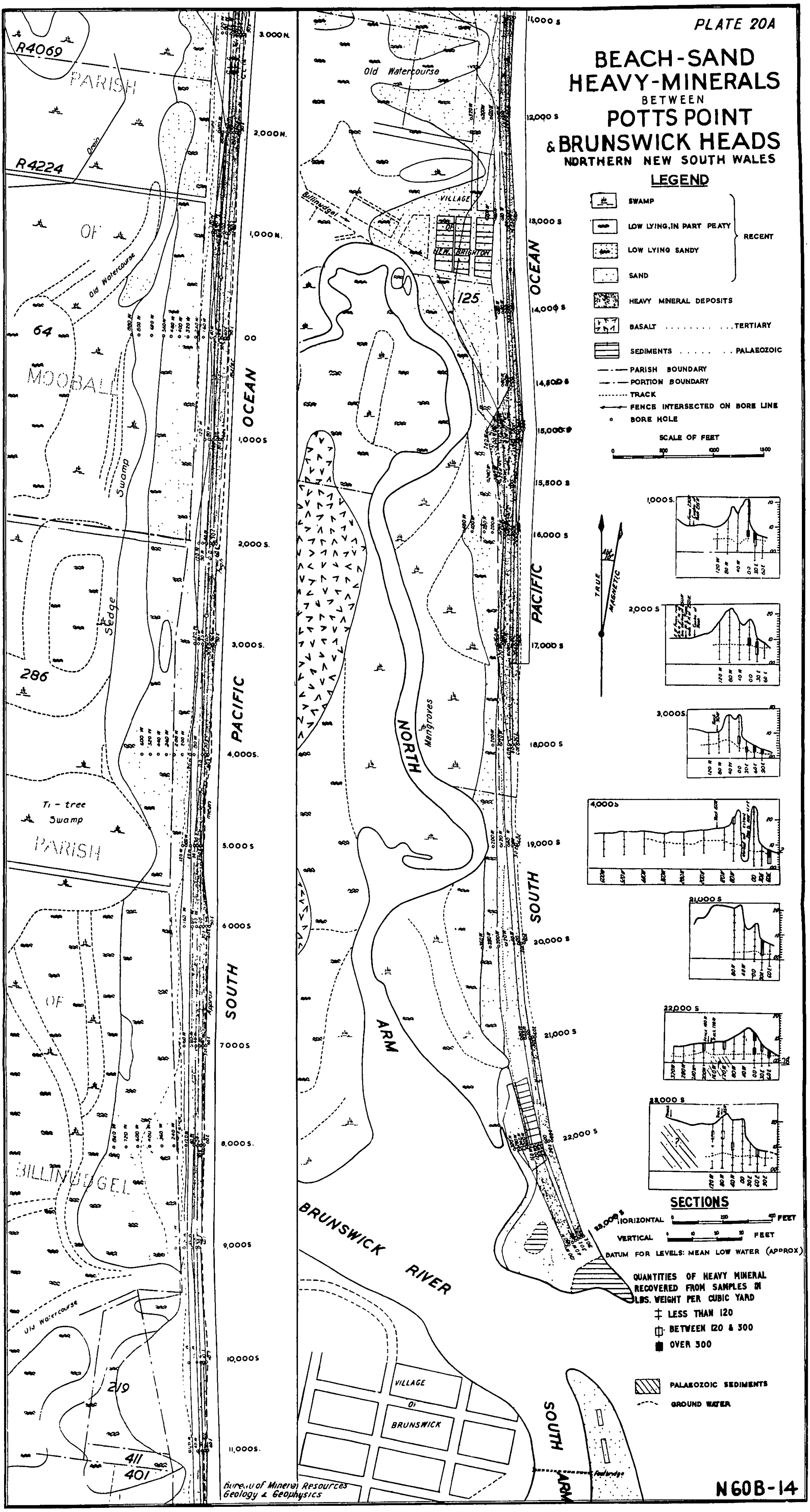


PLATE 20A
BEACH-SAND HEAVY-MINERALS
BETWEEN
POTTS POINT & BRUNSWICK HEADS
NORTHERN NEW SOUTH WALES
LEGEND
SWAMP
LOW LYING, IN PART PEATY
LOW LYING SANDY
SAND
RECENT
HEAVY MINERAL DEPOSITS
BASALT . . . . TERTIARY
SEDIMENTS . . . . . . PALAEOZOIC
PARISH BOUNDARY
PORTION BOUNDARY
TRACK
FENCE INTERSECTED ON BORE LINE
BORE HOLE
SCALE OF FEET
TRUE
MAGNETIC
SECTIONS
HORIZONTAL
FEET
VERTICAL
FEET
DATUM FOR LEVELS: MEAN LOW WATER (APPROX)
QUANTITIES OF HEAVY MINERAL RECOVERED FROM SAMPLES IN LBS. WEIGHT PER CUBIC YARD
LESS THAN 120
BETWEEN 120 & 300
OVER 300
PALAEOZOIC SEDIMENTS
GROUND WATER
PACIFIC OCEAN
SOUTH PACIFIC OCEAN
PARISH OF MOOBALL
PARISH OF BILLINUDGEL
R4069
R4224
Old Watercourse
Drain
Swamp
Sedge
Ti - tree Swamp
64
286
219
411
401
125
VILLAGE OF NEW BRIGHTON
Billinudgel
NORTH ARM
Mangroves
BRUNSWICK RIVER
VILLAGE OF BRUNSWICK
SOUTH ARM
Footbridge
3,000 N.
2,000 N.
1,000 N.
00
1,000 S
2,000 S.
3,000 S.
4,000 S.
5,000 S
6,000 S
7,000 S
8,000 S.
9,000 S
10,000 S
11,000 S.
11,000 S
12,000 S
13,000 S
14,000 S
14,500 S
15,000 S
15,500 S
16,000 S
17,000 S
18,000 S
19,000 S
20,000 S
21,000 S
22,000 S
23,000 S
1,000 S.
2,000 S
3,000 S.
4,000 S
21,000 S
22,000 S
23,000 S
Bureau of Mineral Resources Geology & Geophysics
N 60 B-14

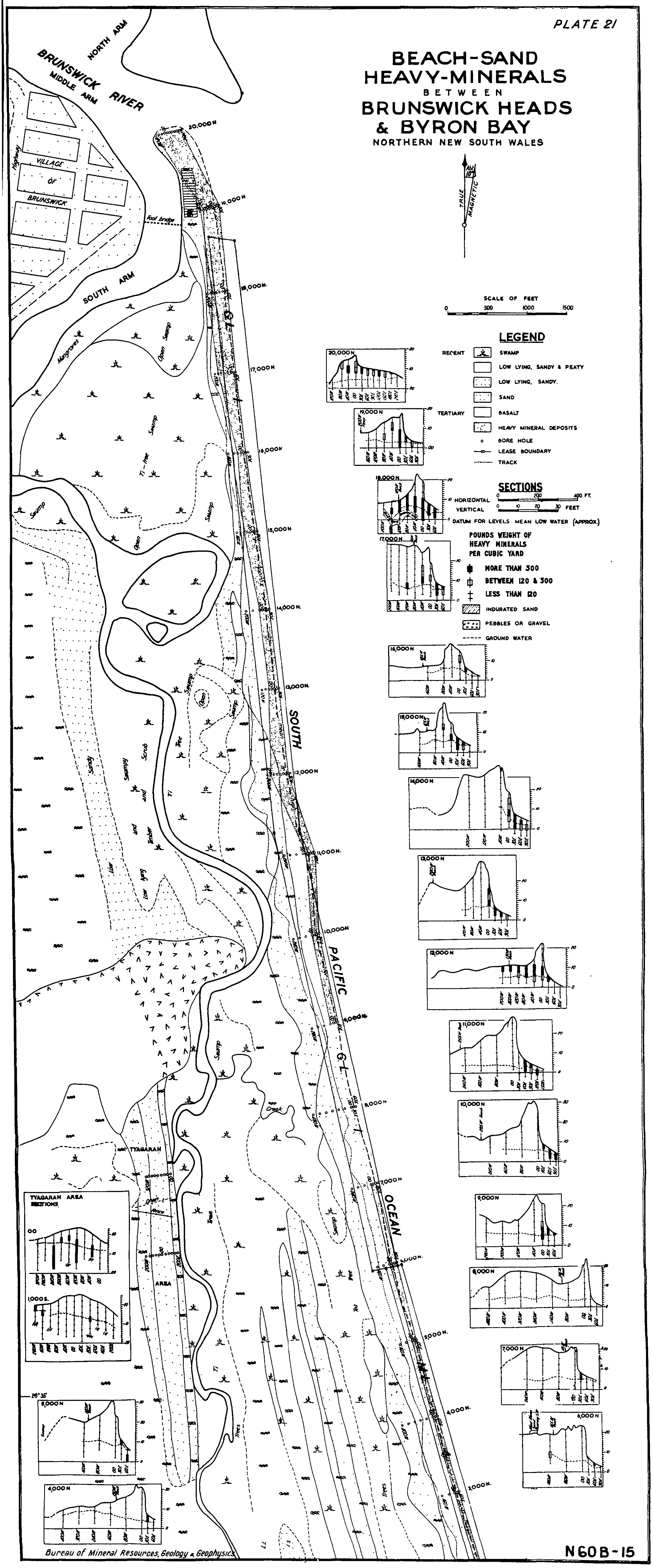


PLATE 21
BEACH-SAND
HEAVY-MINERALS
BETWEEN
BRUNSWICK HEADS
& BYRON BAY
NORTHERN NEW SOUTH WALES
TRUE
MAGNETIC
SCALE OF FEET
0 500 1000 1500
LEGEND
RECENT
SWAMP
LOW LYING, SANDY & PEATY
LOW LYING, SANDY.
SAND
TERTIARY
BASALT
HEAVY MINERAL DEPOSITS
BORE HOLE
LEASE BOUNDARY
TRACK
SECTIONS
HORIZONTAL
VERTICAL
400 FT.
FEET
DATUM FOR LEVELS MEAN LOW WATER (APPROX.)
POUNDS WEIGHT OF HEAVY MINERALS PER CUBIC YARD
MORE THAN 300
BETWEEN 120 & 300
LESS THAN 120
INDURATED SAND
PEBBLES OR GRAVEL
GROUND WATER
NORTH ARM
BRUNSWICK RIVER
MIDDLE ARM
VILLAGE OF BRUNSWICK
Foot bridge
SOUTH ARM
Mangroves
Open Swamp
Ti-tree Swamp
Swamp
Sandy Swampy Scrub and Timber
Low lying
Creek
TYAGARAH
TYAGARAH AREA SECTIONS
AREA
Trees
SOUTH PACIFIC OCEAN
20,000N
19,000N
18,000N
17,000N
16,000N
15,000N
14,000N
13,000N
12,000N
11,000N
10,000N
9,000N
8,000N
7,000N
6,000N
5,000N
4,000N
3,000N
1,000S
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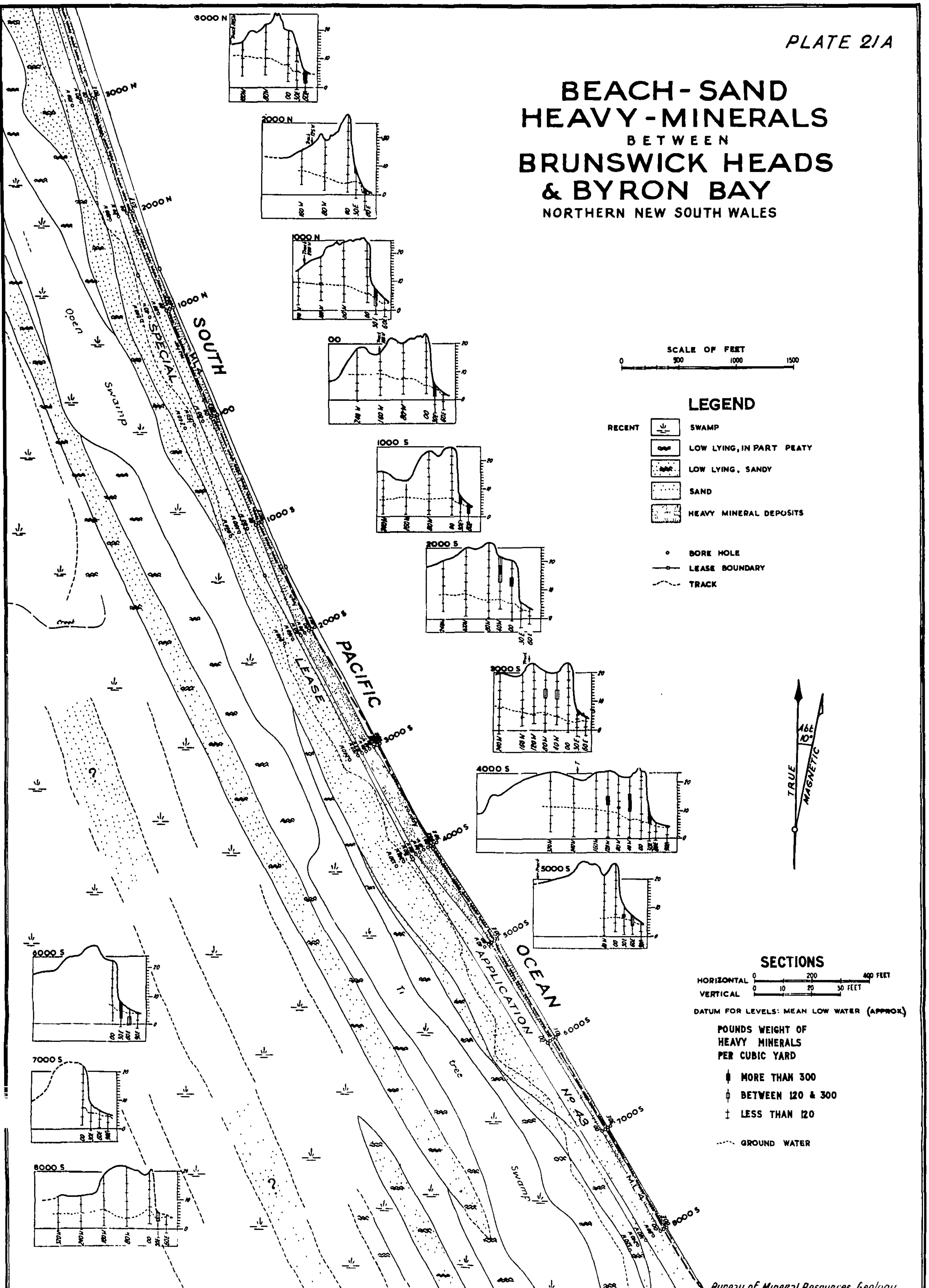
N60B-15

PLATE 21A



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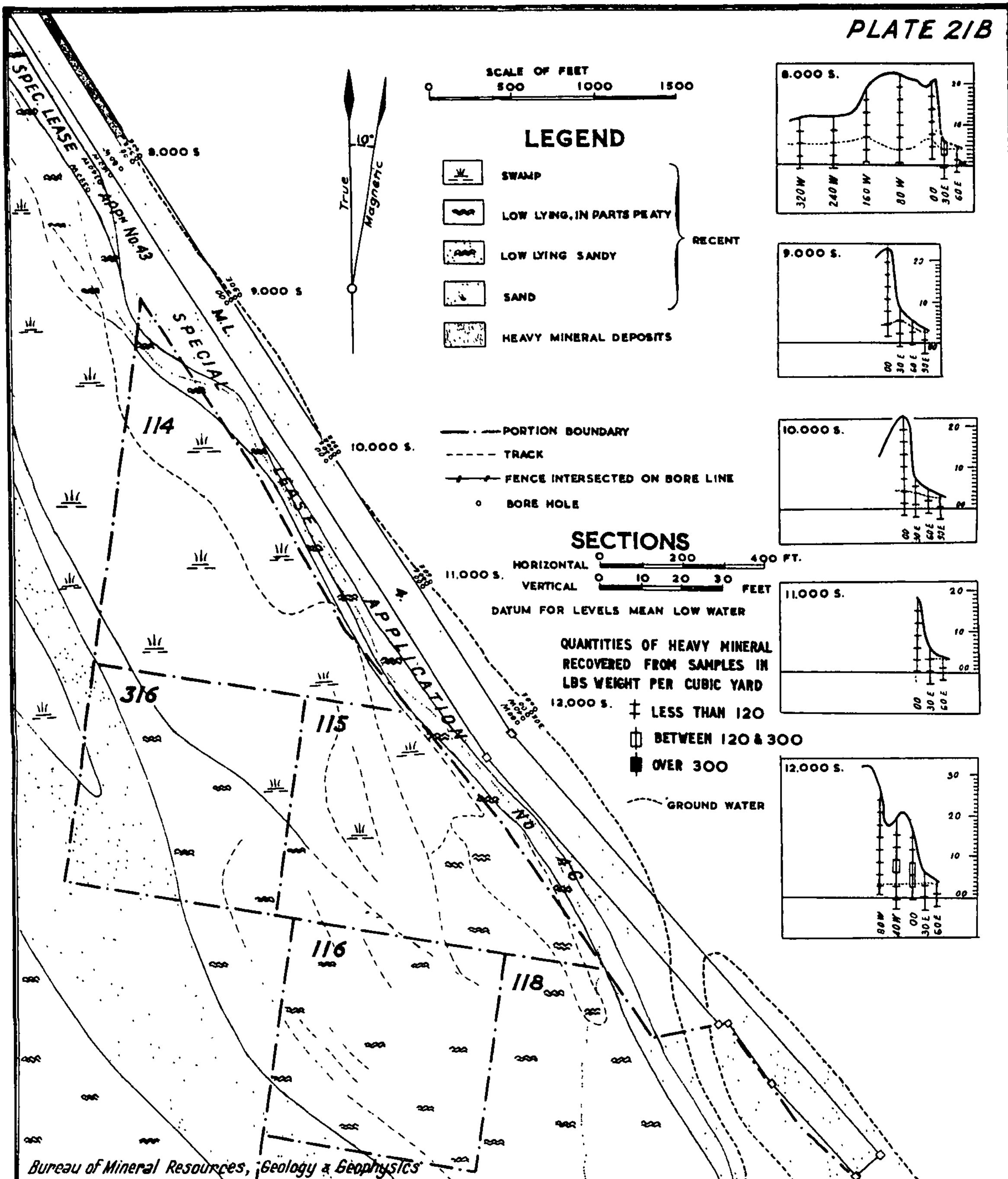
N60B-16

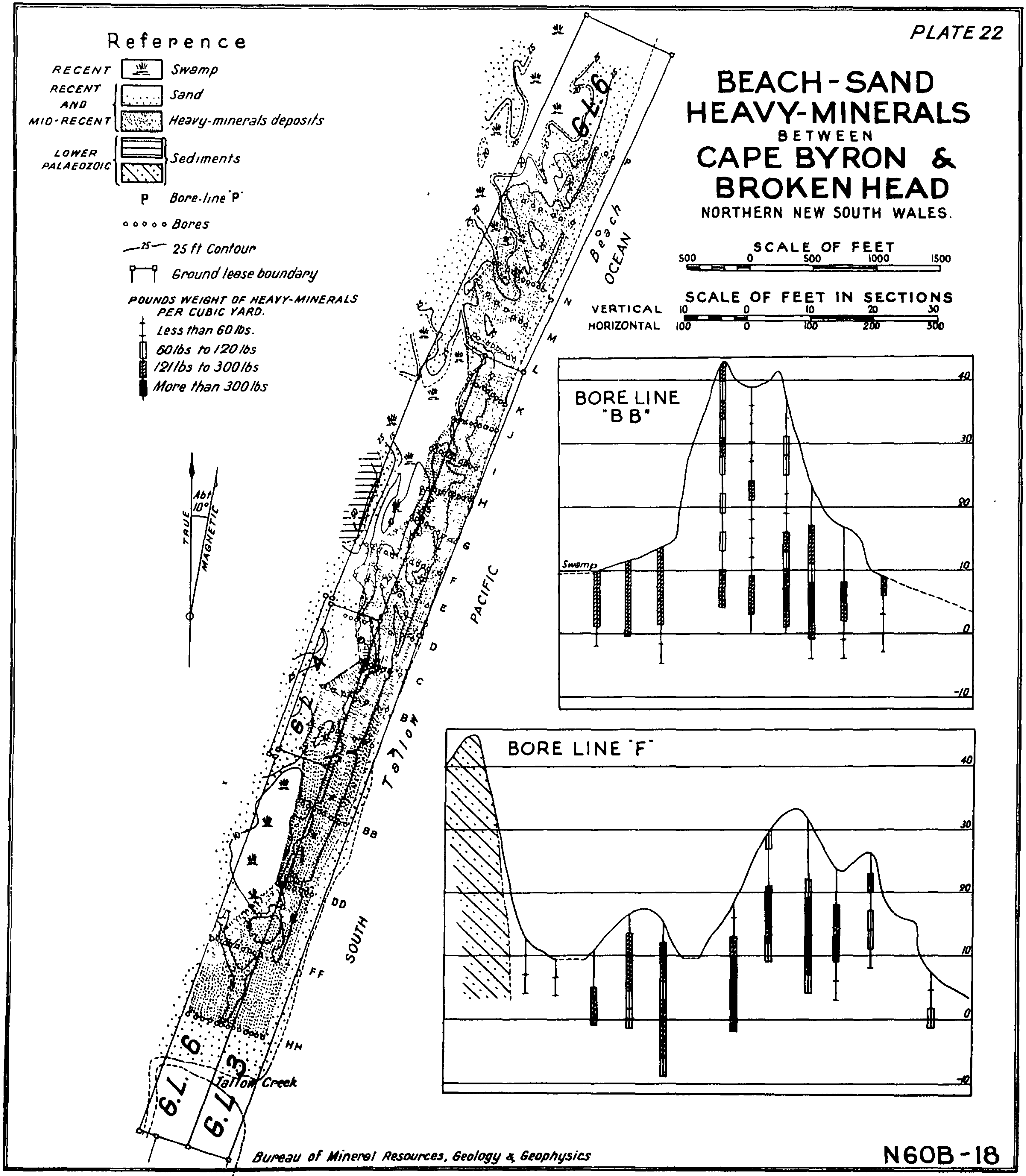
PLATE 2/B



BEACH - SAND HEAVY-MINERALS
BETWEEN
BRUNSWICK HEADS & BYRON BAY
NORTHERN NEW SOUTH WALES

N60B-17

PLATE 22



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N60B-18

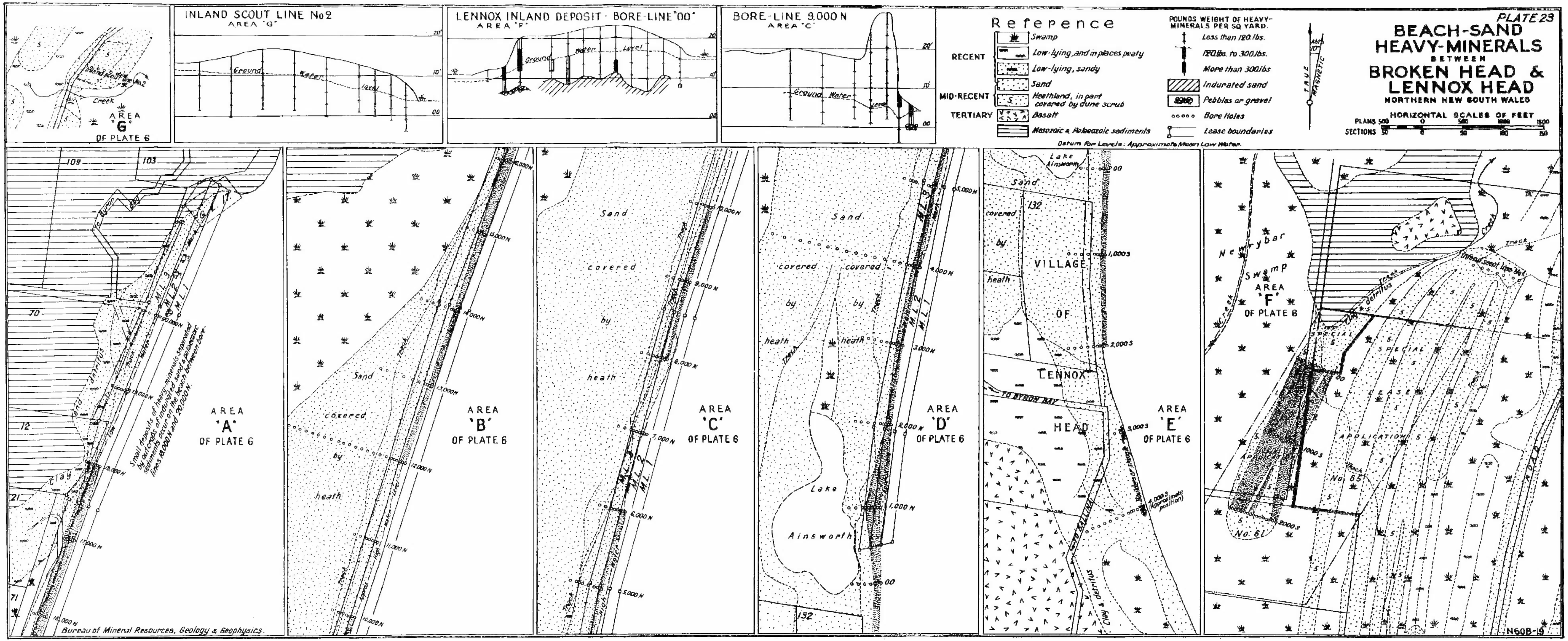
PLATE 23
BEACH-SAND HEAVY-MINERALS BETWEEN BROKEN HEAD & LENNOX HEAD
NORTHERN NEW SOUTH WALES
HORIZONTAL SCALES OF FEET
PLANS 500 0 500 1000 1500
SECTIONS 50 0 50 100 150
Reference
RECENT
Swamp
Low-lying, and in places peaty
Low-lying, sandy
Sand
MID-RECENT
Heathland, in part covered by dune scrub
TERTIARY
Basalt
Mesozoic & Palaeozoic sediments
POUNDS WEIGHT OF HEAVY-MINERALS PER SQ. YARD.
Less than 120 lbs.
120 lbs. to 300 lbs.
More than 300 lbs
Indurated sand
Pebbles or gravel
Bore Holes
Lease boundaries
Datum for Levels: Approximate Mean Low Water.
TRUE
MAGNETIC
INLAND SCOUT LINE No 2
AREA "G"
LENNOX INLAND DEPOSIT · BORE-LINE "00"
AREA "F"
BORE-LINE 9,000 N
AREA "C"
Ground Water Level
AREA 'G' OF PLATE 6
AREA 'A' OF PLATE 6
AREA 'B' OF PLATE 6
AREA 'C' OF PLATE 6
AREA 'D' OF PLATE 6
AREA 'E' OF PLATE 6
AREA 'F' OF PLATE 6
Small deposits of heavy-minerals separated by outcrops of indurated sand & palaeozoic sediments occur on the beach between lines 18,000 N and 20,000 N.
Sand covered by heath
Lake Ainsworth
VILLAGE OF LENNOX HEAD
TO BYRON BAY
Newrybar Swamp
SPECIAL LEASE APPLICATION No. 65
No. 61
Bureau of Mineral Resources, Geology & Geophysics.
N60B-19

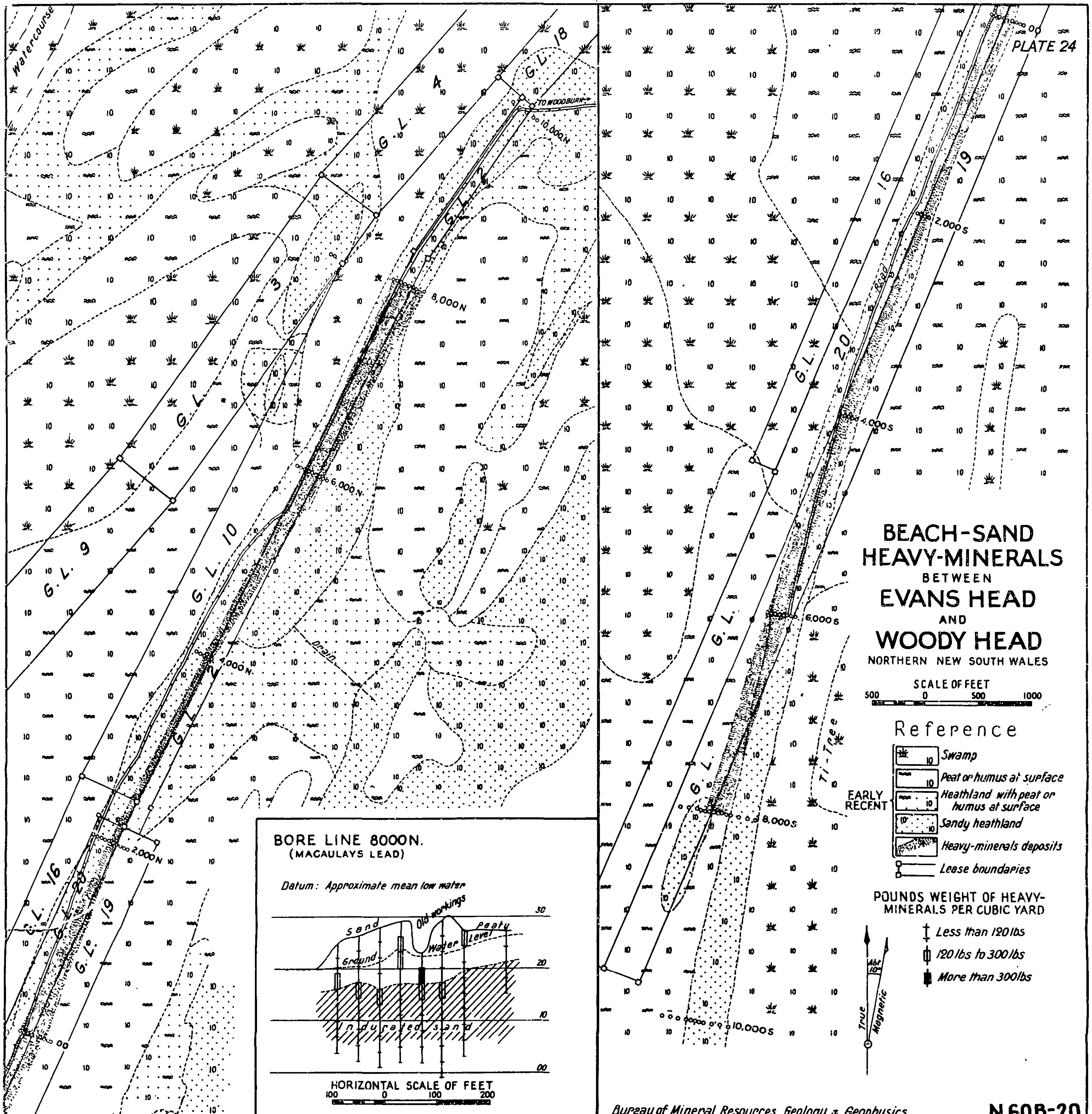
PLATE 24
BEACH-SAND
HEAVY-MINERALS
BETWEEN
EVANS HEAD
AND
WOODY HEAD
NORTHERN NEW SOUTH WALES
SCALE OF FEET
500 0 500 1000
Reference
Swamp
Peat or humus at surface
EARLY RECENT
Heathland with peat or humus at surface
Sandy heathland
Heavy-minerals deposits
Lease boundaries
POUNDS WEIGHT OF HEAVY-MINERALS PER CUBIC YARD
Less than 120 lbs
120 lbs to 300 lbs
More than 300 lbs
True
Magnetic
BORE LINE 8000N.
(MACAULAYS LEAD)
Datum: Approximate mean low water
Sand
Old workings
Peaty
Ground
Water
Level
Indurated sand
HORIZONTAL SCALE OF FEET
100 0 100 200
Watercourse
TO WOODBURN
Drain
Road
Ti-Tree
10,000 N
8,000 N
6,000 N
4,000 N
2,000 N
2,000 S
4,000 S
6,000 S
8,000 S
10,000 S
G.L. 18
G.L. 4
G.L. 3
G.L. 9
G.L. 10
G.L. 16
G.L. 20
G.L. 19
Bureau of Mineral Resources, Geology & Geophysics
N 60B-20

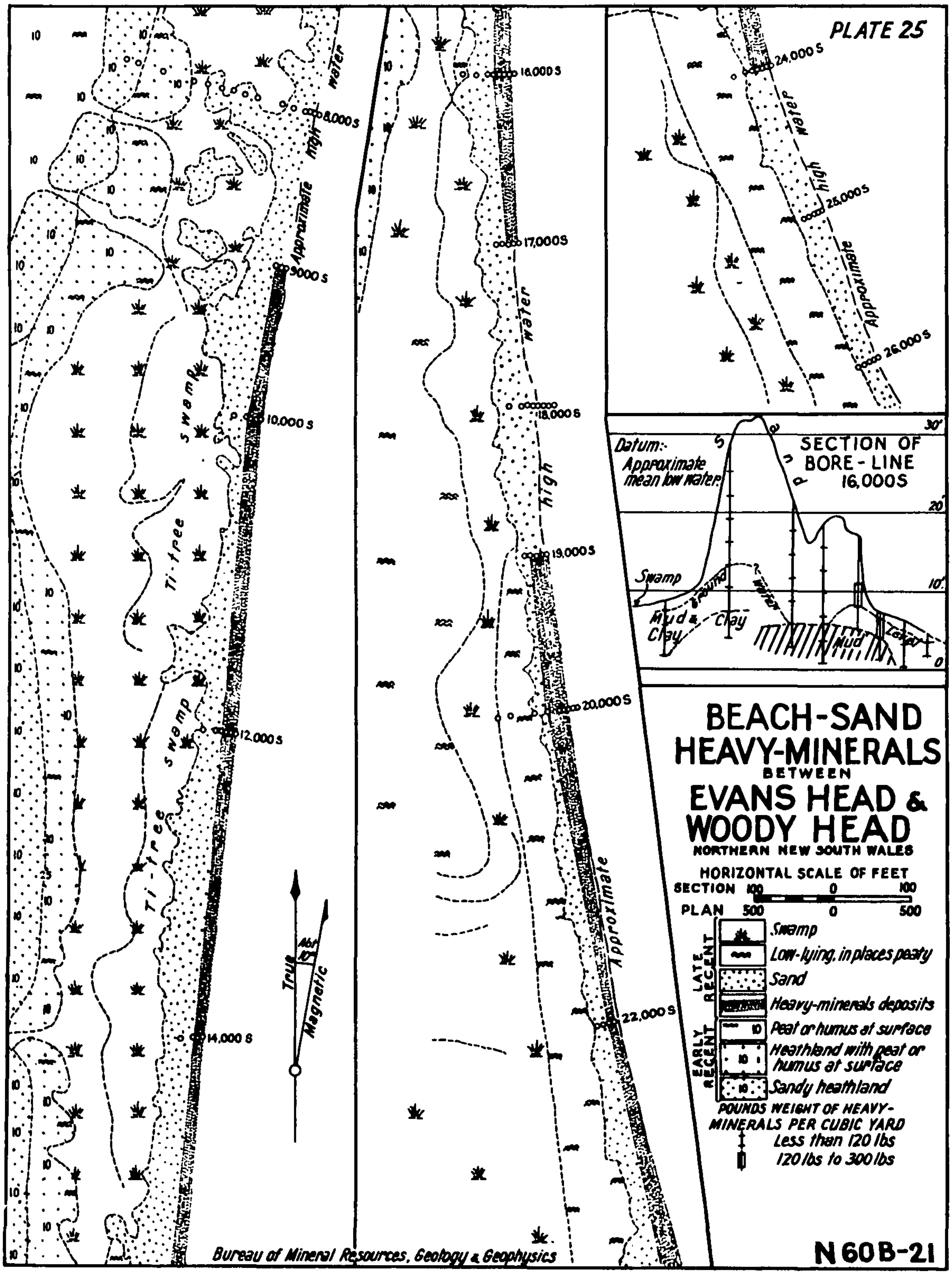
PLATE 25
BEACH-SAND HEAVY-MINERALS BETWEEN EVANS HEAD & WOODY HEAD
NORTHERN NEW SOUTH WALES
HORIZONTAL SCALE OF FEET
SECTION 100 0 100
PLAN 500 0 500
SECTION OF BORE-LINE 16,000S
Datum:- Approximate mean low water
Swamp
Mud & Clay
Clay
Mud
LATE RECENT
Swamp
Low-lying, in places peaty
Sand
Heavy-minerals deposits
EARLY RECENT
Peat or humus at surface
Heathland with peat or humus at surface
Sandy heathland
POUNDS WEIGHT OF HEAVY-MINERALS PER CUBIC YARD
Less than 120 lbs
120 lbs to 300 lbs
Approximate high water
Ti-tree swamp
True
Magnetic
8,000 S
9000 S
10,000 S
12,000 S
14,000 S
16,000 S
17,000 S
18,000 S
19,000 S
20,000 S
22,000 S
24,000 S
25,000 S
26,000 S
Bureau of Mineral Resources, Geology & Geophysics
N 60 B-21

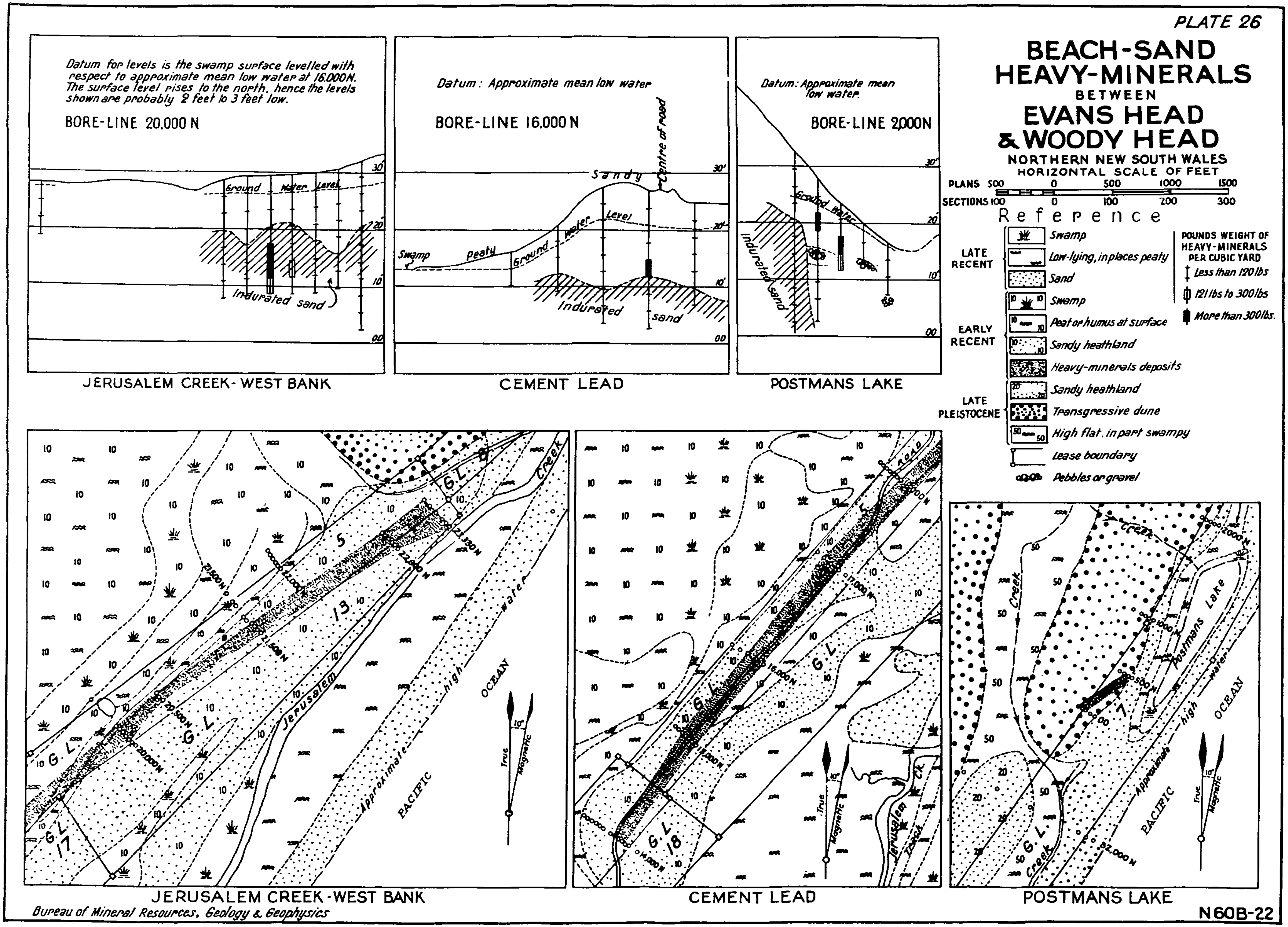
PLATE 26
BEACH-SAND HEAVY-MINERALS BETWEEN EVANS HEAD & WOODY HEAD
NORTHERN NEW SOUTH WALES
HORIZONTAL SCALE OF FEET
PLANS 500 0 500 1000 1500
SECTIONS 100 0 100 200 300
Reference
LATE RECENT
Swamp
Low-lying, in places peaty
Sand
EARLY RECENT
Swamp
Peat or humus at surface
Sandy heathland
Heavy-minerals deposits
LATE PLEISTOCENE
Sandy heathland
Transgressive dune
High flat, in part swampy
Lease boundary
Pebbles or gravel
POUNDS WEIGHT OF HEAVY-MINERALS PER CUBIC YARD
Less than 120 lbs
121 lbs to 300 lbs
More than 300 lbs.
Datum for levels is the swamp surface levelled with respect to approximate mean low water at 16,000N. The surface level rises to the north, hence the levels shown are probably 2 feet to 3 feet low.
BORE-LINE 20,000 N
Ground Water Level
Indurated sand
JERUSALEM CREEK-WEST BANK
Datum: Approximate mean low water
BORE-LINE 16,000 N
Centre of road
Sandy
Swamp
Peaty
Ground Water Level
Indurated sand
CEMENT LEAD
Datum: Approximate mean low water.
BORE-LINE 2,000 N
Ground Water
Indurated sand
POSTMANS LAKE
Jerusalem
Approximate high water
PACIFIC OCEAN
True
Magnetic
JERUSALEM CREEK-WEST BANK
Jerusalem Ck.
CEMENT LEAD
Creek
Postmans Lake
POSTMANS LAKE
Bureau of Mineral Resources, Geology & Geophysics
N60B-22

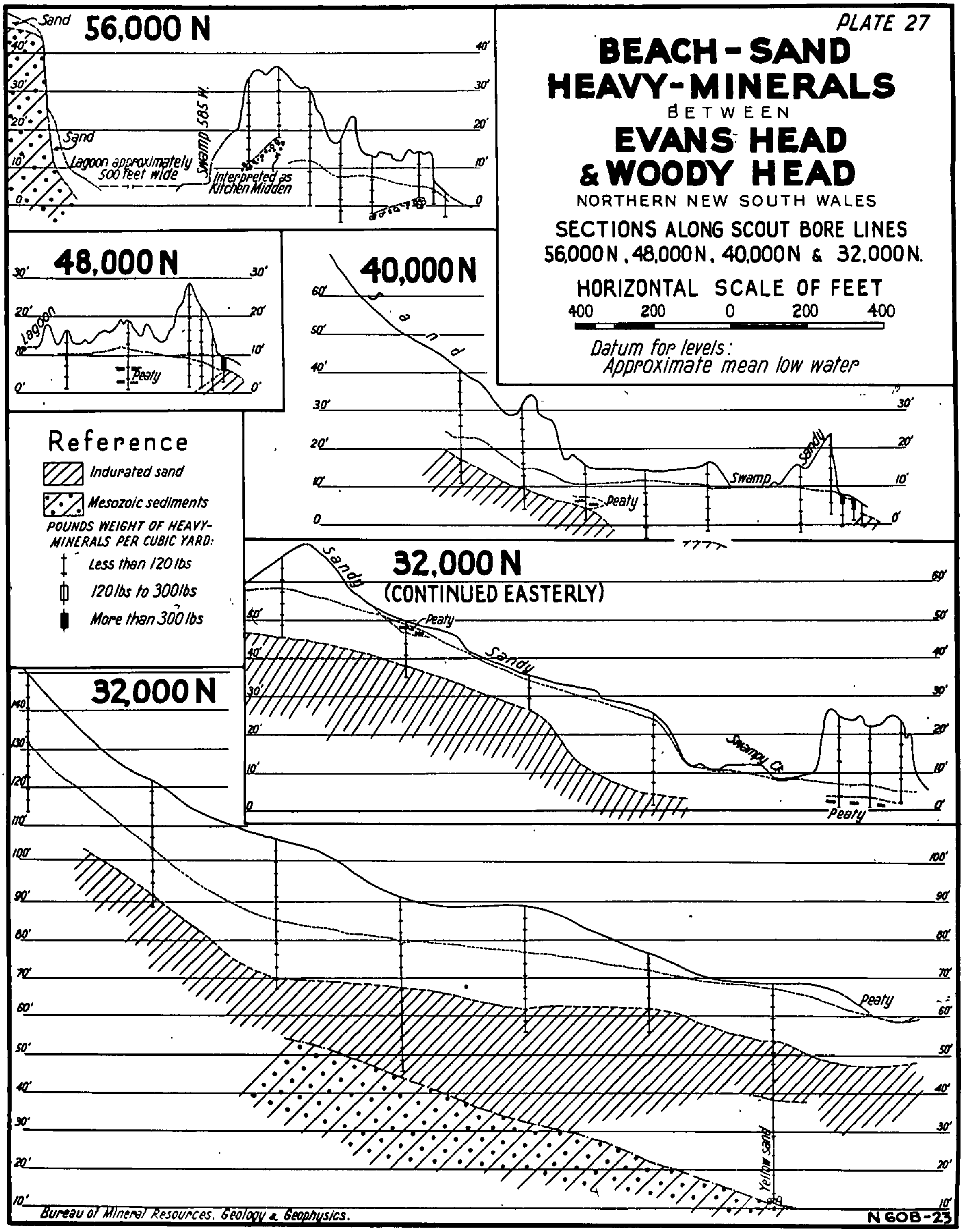
PLATE 27
BEACH - SAND HEAVY - MINERALS
BETWEEN
EVANS HEAD & WOODY HEAD
NORTHERN NEW SOUTH WALES
SECTIONS ALONG SCOUT BORE LINES
56,000 N, 48,000 N, 40,000 N & 32,000 N.
HORIZONTAL SCALE OF FEET
400 200 0 200 400
Datum for levels: Approximate mean low water
56,000 N
Sand
Lagoon approximately 500 feet wide
Swamp 585 W.
Interpreted as Kitchen Midden
48,000 N
Lagoon
Peaty
40,000 N
Sand
Swamp
Sandy
Peaty
32,000 N (CONTINUED EASTERLY)
Sandy
Peaty
Swampy Cr.
32,000 N
Peaty
Yellow sand
Reference
Indurated sand
Mesozoic sediments
POUNDS WEIGHT OF HEAVY-MINERALS PER CUBIC YARD:
Less than 120 lbs
120 lbs to 300 lbs
More than 300 lbs
Bureau of Mineral Resources. Geology & Geophysics.
N 60B-23

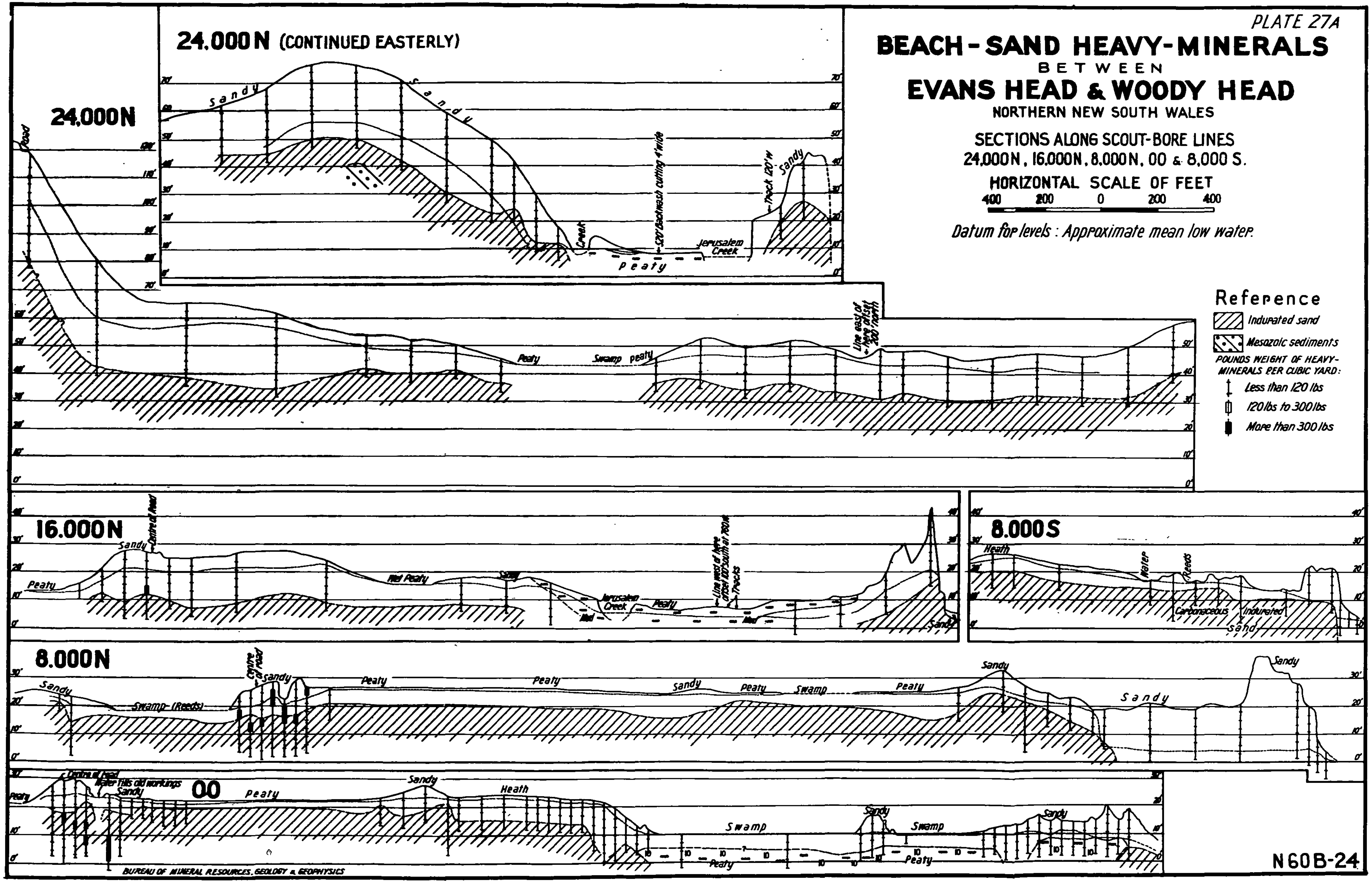
PLATE 27A
BEACH - SAND HEAVY - MINERALS
BETWEEN
EVANS HEAD & WOODY HEAD
NORTHERN NEW SOUTH WALES
SECTIONS ALONG SCOUT-BORE LINES
24,000 N, 16,000 N, 8,000 N, 00 & 8,000 S.
HORIZONTAL SCALE OF FEET
400 200 0 200 400
Datum for levels : Approximate mean low water.
Reference
Indurated sand
Mesozoic sediments
POUNDS WEIGHT OF HEAVY-MINERALS PER CUBIC YARD:
Less than 120 lbs
120 lbs to 300 lbs
More than 300 lbs
24,000 N (CONTINUED EASTERLY)
24,000 N
16,000 N
8,000 S
8,000 N
00
Sandy
Peaty
Swamp
Heath
Jerusalem Creek
Creek
Road
Track 120' W
Reeds
Water
Carbonaceous
Indurated Sand
Swamp-(Reeds)
Centre of road
Water fills old workings
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