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THE HEAVY MINERAL DEPOSITS OF THE EAST COAST OF AUSTRALIA.

by

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GEOGRAPHICAL DISTRIBUTION.

The most important known deposits of what are commonly referred to as the beach sand minerals are situated along the most easterly part of the Australian coast, between Southport, 17 miles north of the Queensland-New South Wales border, and Ballina, 50 miles south of the border, and most of the production has come from this area. Smaller deposits are known to occur farther to the south at intervals for several hundred miles, and beaches have been worked at Yamba, 96 miles south and Woolgoolga, 150 miles south of the border and at Swansea, 60 miles north of Sydney. Important deposits have been shown to exist on North Stradbroke Island and others have been located farther to the north, as far as Tin Can Bay at the south end of Frazer Island. (FigureI).

Table I. gives the list of operators with the location of their deposits and workings, their approximate maximum monthly capacity expressed in tons of heavy mineral produced by their concentrating plants before separation into individual mineral concentrates, their methods of mining and concentrating the minerals, and the products obtained. This table applies at June, 1948, but all the operators are remodelling or improving their plants and plant practices will be modified accordingly.

In addition active boring campaigns have been carried out by Alluvial Gold, Limited, of Sydney, in the Cudgen-Cudgera area, and by Zinc Corporation Limited, of Melbourne, on Stradbroke Island, and in other places.

PHYSIOGRAPHY.

Submergence of the order of 100 to 200 feet at the close of the Pleistocene Period left the pre-existing hills as promontories and the valleys as deep inlets. Wave action has built bay-bars and sandspits (Figure 2) in a northerly direction from the headlands, and lakes and marshes have formed between these bars and the initial post-submergence coastline (Figure 3). These lakes and swamps have been or are being filled in by river-borne sediments or wind-blown sand. Beasley (1947) has presented evidence that suggests a recent emergence of the coastline of about ten feet. The evidence for this belief is the presence of a black sand seam ¼ mile inland and 17 feet above sea level, (Figure 4) and although it is not entirely certain that this seam is of beach formation and owes nothing to wind-blown concentration, other evidence supports the suggestion of recent emergence. Such emergence would undoubtedly aid the formation of bars and sandspits and the easterly progress of the beach front, leaving a series of parallel dunes. (Figure 5).

This belt of north-south coastal dunes ranges up to ½ mile in width and as many as 15 lines of dune have been counted (Figure 4). The foredune is generally the highest, up to 25 feet high, and there is in many places a flat platform in front of the dune known as the berm. (Figure 7). The dunes behind the foredune are lower and less well defined and the most landward dunes are generally broadest (Figure 8). The width of the beaches at low tide is 100 to 200 feet.

TABLE I.

PRINCIPAL BEACH SAND OPERATORS, JUNE, 1948.

Operator.	Location of Plant 1. and Deposit 2.	Approximate Monthly throughput, (as mixed concentrates). tons.	Method of Mining.	Outline of Treatment Method	Products marketed
Mineral Deposits Syndicate	1. Southport, Qld., 17 miles north of N.S.W. Border. 2. Broadbeach - Burleigh Area.	600	Stripping overburden by bulldozer, selective hand-loading into motor trucks, replacement of overburden.	Wilfley tables, draining, rotary drier, rotary magnetic separators to eliminate ilmenite, electrostatic separation of zircon-rutile, cleaning by magnetic separator.	Zircon 85% Rutile 95% Zircon-rutile 55-40
Associated Minerals.	1. Southport, Queensland. 2. Southport - Broadbeach Area.	500	Stripping overburden by bulldozer, selective hand-loading into motor trucks, replacement of overburden.	Wilfley and curvilinear tables, rotary drier, electromagnetic and electrostatic separation of zircon and rutile, with further cleaning of each product by both electrostatic and electromagnetic methods.	Zircon 93% Rutile 96%
Rutile Sands Pty.	1. Currumbin, 6 miles north of border. 2. Tugun and Currumbin beaches.	650	Stripping overburden with small bulldozer. Selective hand-loading into motor trucks.	Wilfley tables, draining, rotary drier, electrostatic and electromagnetic separation.	Zircon 90% Rutile 96%
Tweed Rutile Syndicate	1. Cudgen Beach, N.S.W. 9 miles south of border. 2. Cudgen and adjacent beach area.	500	Stripping overburden with horse-drawn scoops; loading motor trucks with diesel shovel.	Wilfley tables, conveyor to drier, electrostatic and electromagnetic separating and cleaning.	Zircon 95% Rutile 96% Zircon-rutile 60:40
Titanium Alloy Manufacturing Co.Ltd.	1. Cudgen beach, N.S.W. 10 miles south of border. 2. Cudgen and adjacent beach area.	900	Removal of overburden by power scoops and piling of heavy mineral which is loaded by small drag-line scraper into 2' gauge railway trucks drawn by diesel locomotive.	Wilfley tables, draining, rotary drier; 6 electrostatic units; removal of ilmenite by Exolon magnetic separator.	Zircon 98% Rutile 96%
Metal Recoveries Ltd.	1. Crabbe's Creek and Mooball Siding, N.S.W, 24 miles south of border. 2. Cudgera to New Brighton.	250	Removal of overburden by horse scoops, selective hand loading into lorries.	Wilfley and curvilinear tables at Crabbe's Creek. Concentrates carted to Mooball, dried, passed through Exolon electromagnetic separator and through electrostatic separator.	Zircon 97% Rutile 97% Zircon-rutile - varialbe grade.
Zircon Rutile Ltd.	1. Byron Bay, N.S.W. 34 miles south of border. 2. Seven Mile and Tallow Beach, Byron Bay.	1000	Overburden removed and heavy mineral stacked and loaded into motor trucks by overloader; a drag-line loader is also used.	Wilfley tables at beach, concentrates carted to main plant at Byron Bay, zircon taken out by flotation, tailings passed over cleaner curvilinear tables, then through drier and ilmenite and other slightly magnetic minerals removed magnetically; zircon concentrate is dried and cleaned magnetically.	Zircon 99.5% Rutile 96%
Swansea Minerals *	1. Swansea beach, 60 miles north of Sydney. 2. Swansea.	300	Hand-loading into lorries.	Wilfley tables only.	Mixed concentrate Zircon44% Rutile10% Ilmenite 41% Others 5%

* Not working at present.

MANNER OF FORMATION OF THE HEAVY MINERAL SEAMS.

The heavy mineral deposits are formed initially on the beaches, between low water mark and the highest point reached by storm waves at high tide, by the concentrating action of the surf waves on the heavy mineral content of the beach sands, which in general is considerably less than 1 per cent - probably of the order of 0.1 per cent. The east coast of Australia is in the belt of the south-east trades and is exposed to continual south-easterly winds. Most of the work of concentrating the heavy minerals is done during storms, particularly during the very violent storms accompanied by fierce gales whichoccur only once every few years.

Essential conditions for the formation of a deposit apparently include -

(1) a stretch of beach running nearly north-south with a high dune at the back and open sea unobstructed by islands or headlands in front,

(2) a headland, rock outcrop or other natural bar or a river or creek mouth at the north end of the beach, and

(3) an adequate source of heavy minerals in the rock formations of the adjacent areas.

The heavy seas whipped up by the gales strike the beach at an angle (Figures 2 and 5) and the surf dashes up the beach and to the right, i.e. in a northerly direction. The returning water has sufficient velocity to carry only the quartz sand with it leaving a residual concentration of the heavy minerals. The result of this process is that there is a continual northerly movement of the heavy mineral along the beaches and deposits tend to be ephemeral unless they are anchored at the north end by some natural bar. In such cases the deposit builds southward and may attain several miles in length.

Ocean currents do not appear to play an important part, as the general offshore current along the East Coast of Australia flows in a southerly direction with a velocity of 1½ to 2 knots, although this may be reduced, or even reversed in places, near the shore (Halligan, 1921).

The whole cycle of processes involved in the concentration of the heavy minerals may be summarised as follows -

1. During normal weather wave action gradually moves sand on to the beach and builds up the beach profile to a comparatively steep angle, approximately 8 degrees.
2. Strong winds, usually from the south-east, blow the lighter quartz sands towards the dunes and leave the heavy minerals concentrated in a thin layer, less than ½ inch, on the beach. Repetition of this process may form a series of thin black layers separated by ordinary beach sand.
3. Storm waves as described above concentrate the black sands, remove the quartz and flatten the beach profile to about 4 degrees, leaving a wave-cut cliff at the inshore side of the beach.

Recent prospecting on Stradbroke Island indicates that stage 2 may locally be of much greater importance than was previously realised and that high dunes containing large low-grade deposits of heavy mineral may be built up by strong winds continually robbing the beaches of their wave-borne heavy mineral content.

From the manner of their formation the individual beach deposits tend to be lenticular in cross-section and their distribution is erratic unless they are stabilised by a protecting bar at the north end of the beach as indicated above. They extend from somewhere between high and low water mark to a point reached by the strongest storm waves some distance above the high water mark. The deposits become thinner towards the south (Figure 9), and may split into two or more seams. In cross-section they feather out gradually on the seaward side as the almost flat base converges with the slope of the beach surface. At the landward side they terminate rather abruptly, immediately after attaining maximum thickness, which may be as much as 5 feet but is usually only 1 or 2 feet in individual seams (Figures 10 to 18). They are usually not more than 50 feet in width, except in cases where the deposit has grown gradually seawards with a slow easterly progression of the beach, and extends continuously through more than one line of dunes.

The building up of a large deposit is a process which takes a considerable number of years although it is not a slow process by geological standards of time. Statements have been made that beach deposits that have been worked out are regenerated by severe storms but this happens only where part of the northerly section of the beach has been worked and storms have moved heavy mineral northwards from the unworked section to the "vacant" space made available by the workings, or where only high-grade concentrate has been mined from a deposit, leaving sufficient black sand in overburden or rejected narrow seams to be reconcentrated into one workable seam. No case has been observed of regeneration of a deposit that has been thoroughly worked.

The position of the water-table relative to the base of the deposit is important to the operator and in most cases, particularly where a line of dunes is flanked on the landward side by low swampy areas, the water-table obviously corresponds to sea-level and approximately to the base of the deposit. Where rising ground occurs behind the deposits, the water-table may show a corresponding rise and in suchcases seams may be found below ground-water level. However, no concentrations of heavy minerals have been found below sea-level (at low tide).

ORIGIN OF THE HEAVY MINERALS.

The black sand deposits, as explained above, are merely the result of the concentration of the heavy mineral content, usually about 0.1 per cent, of the beach sands, and are likely to occur anywhere that a suitable combination exists of coast orientation relative to prevailing winds and currents. Thus deposits are known to exist at intervals all along that part of the east coast of Australia, south of the Great Barrier Reef, that is exposed to the south-east trades. However, the relative abundance and richness of the deposits in the area from Ballina to Stradbroke Island must be related to the existence of a comparatively prolific source of zircon, rutile and ilmenite in the mainland rocks of the area. The main immediate source has usually been assumed to be the freshwater sandstones of the Clarence Series of Triassic-Jurassic age, with some contribution of ilmenite from the basalts of the Ballina-Point Danger area. The original source of most of the zircon, rutile, monazite, and part of the ilmenite is undoubtedly the extensive Permian granite masses of the New England area (Figure 1), which extend from just north of the Queensland border south for 250 miles. After erosion of the granite these minerals have eventually found their way to the beaches, either via the Clarence Sandstones or more directly by way of the present major streams of the North Coast area, which rise in, or adjacent to the granite. The principal stream is the Clarence River which enters the sea near Yamba, 96 miles south of the border and this river, together with the Richmond which comes out at Ballina, (or their ancestral streams) is considered to have been the main avenue of delivery of heavy minerals to the ocean sands.

Beasley (1947) found that a sample of the Clarence sandstones from near Byron Bay gave a good yield of heavy mineral of the approximate composition - Rutile 50 per cent, Zircon 25 per cent, Ilmenite 15 per cent, others 10 per cent. A sample of greywacke obtained inland from Southport gave a small yield of minerals consisting of 85 per cent Zircon, 10 per cent Ilmenite and 5 per cent other minerals. (In the Sydney area samples from beach deposits taken between Port Kembla 50 miles south to Swansea 50 miles north of Sydney gave a zircon-rutile-ilmenite ratio of approximately 44:14:42 and Whitworth (1931) has recorded heavy mineral contents of the Triassic sandstone about Sydney with a zircon-rutile-ilmenite ratio of 40:15:45. Samples of concentrates from Swansea gave a zircon-rutile-ilmenite ratio of 46:11:43).

COMPOSITION.

The heavy mineral content of the deposits that have been worked ranges from 20 to 80 per cent, but probably averages, in the feed to the concentrating tables, 40 to 50 per cent by volume. Most of the operators practise selective mining in addition to removal of overburden, which may be as much as 20 feet thick (Figures 10 and 11), and where practicable discard barren or low-grade seams.

The mineral composition of the heavy mineral concentrates obtained ranges in general from 44 to 70 per cent zircon and 15 to 35 per cent each rutile and ilmenite.

The concentrates considered as a zircon-rutile-ilmenite product are remarkably clean. The sum of the other heavy minerals seldom exceeds 5 per cent and is usually about 2 or 3 per cent. The most abundant of the minor constituents are garnet, monazite, tourmaline and cassiterite, but the amount present of any one of these rarely exceeds 1 per cent, although local concentrations of garnet have been noted. Other minerals recorded include spinel, leucoxene, epidote, chromite, pyroxenes, andalusite and staurolite. Table 2 gives the approximate average composition of the concentrates from representative beaches, obtained partly by grain counts carried out by A.W. Beasley (1947), by H.F. Whitworth of the New South Wales Department of Mines and by the Bureau of Mineral Resources, partly from production records or other information supplied by the operating companies.

The proportions of zircon, rutile and ilmenite in the concentrates have been plotted relative to distance north of the mount of the Clarence River (Figure 19). The graph illustrates rather strikingly a gradual decrease in the proportion of zircon and an increase in rutile and ilmenite as far as South Stradbroke Island, then an abrupt decrease in zircon and increase in ilmenite, while rutile decreases slightly. North of Stradbroke Island, the composition remains fairly constant. The writer's interpretation of these variations is as follows. What may be termed the normal proportion of zircon, rutile and ilmenite in natural concentrates derived from the rocks of south-east Queensland is approximately that found north of Stradbroke Island, ivz. 22:16:62. The principal source of zircon is the streams draining the area occupied by the Clarence sandstones and the New England granite, of which the main one is the Clarence River. This area has also contributed a relative enrichment of rutile. As the minerals were drifted northwards along the coast the variation in composition as far as South Stradbroke Island was only such as might be accounted for by minor local additions, particularly of ilmenite from the basalt areas, and differences in distribution due to the relative specific gravities of the various minerals. North Stradbroke Island, which is 24 miles long, 7 miles wide at the northern end, with an area of approximately 107 square miles, is built up almost entirely of sand dunes, rock outcrops being confined to a very small area at the northern end. (The sand dunes on Stradbroke reach a maximum height of 719 feet and those on Moreton Island to the north, which is similar in every way, (Figure 20), have a maximum height of 919 feet). These islands, and particularly Stradbroke have acted as a vast sand trap and have held the "excess" minerals drifting along the coast from the Clarence area. Hence north of Stradbroke the composition of the concentrates returns to the "normal" for the south-east Queensland area, and stays constant, as the influence of the Clarence Series and the New England granite has failed to penetrate north of Stradbroke Island.

Another implication of the mineral distribution along the coast is that zircon is a relatively late addition, at least as far as the more northerly beaches are concerned. This is confirmed by the composition of the old raised beach in the Burleigh area, referred to earlier (Figure), where Beasley (1947b) by grain-count recorded the following compositions: Zircon 37.0 per cent; rutile 21.2 per cent; ilmenite 38.5 per cent; other minerals 3.3 per cent, as compared with the average for the seams being worked near the beach level in the same area of zircon 50 per cent; rutile 22 per cent; ilmenite 25 per cent; other minerals 3 per cent. The reason for this apparent late enrichment of the zircon content of the deposits has yet to be determined.

TABLE II.

Approximate Average Composition of Heavy Mineral Concentrates.

Locality	Zircon	Rutile	Ilmenite	Other Minerals.
Collaroy	40	15	43	2
Swansea	44	11	41	4
Woolgoolga	28	34	25	3
Wooli	70	10	18	2
Yamba	70	13	15	2
Ballina	62	17	15	5
Byron Bay	54	26	19	2
New Brighton	50	25	23	2
Cudgen	48	27	23	2
Currumbin	51	25	22	2
Palm Beach	49	25	23	3
Burleigh	50	22	25	3
Broad Beach	45	28	25	2
S. End Stradbroke Is.	43	27	26	4
S. Stradbroke Is.	30	24	44	2
N. Stradbroke Is.*	26	16	56	2
S. Moreton Is.	23	20	55	2
N. Moreton Is.	21	15	60	4
Bribie Is.	18	19	50	3
Caloundra	21	18	58	3
Noosa.	19	14	62	4

A point of special interest with regard to the ilmenite of the East Coast beaches is its chromium content, which ranges in assays made of the clean ilmenite concentrates up to 5.2 per cent Cr_2O_3. Information at present available indicates that the chromium is present partly as chromite grains, which follow the ilmenite in the separation processes employed, and partly in combination within the ilmenite. Further work is required to determine

* More recent grain counts of beach samples averaged Zircon 30; Rutile 34.5; Ilmenite 29.5; others 6 (Connah, 1948).

the distribution of the chromium more exactly. The composition of the pure ilmenite apparently corresponds to the standard formula for ilmenite ($FeO.TiO_2$) with a theoretical TiO_2 content of 52.7 per cent.

RESERVES.

At the present time it is not possible to give any concise figures for reserves of the beach sand minerals. Boring campaigns are being carried out and much further work will be done in connection with the Commonwealth Government's campaign to determine accurately the monazite reserves. Although the beaches on which deposits occur are distributed along more than 100 miles of coast, the reserves contained in the actual beach deposits are obviously limited and probably would not be sufficient to maintain production at the present rate (21,576 tons of zircon and 13,194 tons of rutile in 1947) for more than ten or possibly twenty years. However, very much larger reserves are contained in the deposits belonging to earlier sand dunes behind the present beaches, particularly in the Byron Bay, New Brighton-Cudgera, Cudgen and Currumbin-Southport areas and on North Stradbroke Island. Recent boring in the old dunes behind the beach in the Cudgen area (Figure 5) has indicated large reserves. Boring has shown that many deposits of workable grade exist in the old dune lines on the Queensland side of the border but the quantities available in this section are drastically reduced by the fact that as this is Queensland's and, in the opinion of most of those who have visited there, Australia's premier pleasure resort, the land has mostly been taken up for residential purposes and much of it has already been built upon. The most significant results obtained recently with regard to reserves however are those obtained by Zinc Corporation Limited on Stradbroke Island. West of the coastal dunes along the east coast of Stradbroke Island is a swamp up to ½ mile in width and behind this againare old dunes 200 feet or more inheight. Boring with a hand-operated posthole auger to a maximum depth of 22 feet on these dunes disclosed the presence at least to that depth of up to 10 per cent of heavy minerals, obviously of wind-blown origin, containing approximately 30 per cent zircon, 25 per cent rutile and 45 per cent ilmenite (private communication). Although the average heavy mineral content indicated by these bores is probably not more than 3 per cent, the enormous quantities of sand that appear to be present give promise of very large reserves of zircon, rutile and ilmenite. Deep boring with a power driven plant has confirmed the results of the shallow boring and further work is at present being undertaken to test the mineral content of the high dunes thoroughly. The effects of the discovery of these large quantities of zircon and rutile upon the economy of the zircon-rutile industry, both with regard to operators and to consumers, has yet to be determined and is at present being investigated.

ACKNOWLEDGEMENTS.

In addition to the papers listed in the Bibliography the writer has had access to many unpublished reports prepared by officers of State and Commonwealth Government Departments and private companies, and has closely followed the progress of the beach sand industry since 1942. I would like to record my appreciation of the ready co-operation and friendliness of the operators who have always been ready to provide information and discuss problems of heavy mineral occurrence. In particular I wish to thank Mr. A.W. Beasley, who spent two years, 1945 and 1946, carrying out research work on the beach sands of Southern Queensland, for allowing me the use of his manuscript in advance of publication and for providing the photos which constitute figures 3 and 6 to 18 of this paper.

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