Marine environments of economic mineral deposition around New Zealand: A review

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MARINE ENVIRONMENTS OF ECONOMIC MINERAL DEPOSITION AROUND NEW ZEALAND: A REVIEW

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SUMMARY

Concentrations of minerals on the sea floor around New Zealand occur in a manner which makes them economically significant as future mineral resources.

Three major environments of interest are beaches, the continental shelf, and the adjacent deep-sea floor. New Zealand's west coast beaches are well known as mineral resources containing large quantities of iron and titanium ores. Similar concentrations representing fossil beaches are also known from the continental shelf. The deep-sea floor adjacent to the continental shelf is formed around New Zealand by the New Zealand Plateau, an extensive submarine platform in 500–1,500 m. Terrigenous sedimentation is negligible in this environment where, as a result, pure calcareous oozes are common. Vigorous bottom currents and suitable reducing micro-environments encourage glauconite formation. In the past, possibly from warmer waters of the early and mid Tertiary, phosphates were precipitated from seawater to form phosphorite nodules, a potential resource of phosphates. During late Tertiary or Quaternary, volcanicity at the Antipodes Islands and on the Macquarie Ridge resulted in the formation of manganese deposits. Manganese minerals also occur in bulk on the floor of the Southwestern Pacific Basin away from the New Zealand Plateau.

The origin, bulk, and significance of these deposits are discussed.

INTRODUCTION

This review deals with those minerals of organic or inorganic origin which are concentrated on the sea floor around New Zealand in a manner which makes them mineral resources of potential economic worth.

The sea covers 71 per cent of the surface of the earth. It is a vast reservoir of mineral matter either in solution or forming minerals on the sea floor. Hitherto this mineral matter has been exploited to a rather limited extent only, but this state of affairs reflects the lack of knowledge concerning the sea rather than a deficiency of mineral wealth. It also reflects the poorly developed technology of ocean mining and the absence of a suitable economic incentive to exploit or even explore these resources.

Four major offshore environments of mineral deposition may be delineated. (a) Beaches are well known as mineral deposits, and their minerals are mined in several regions of the world. (b) The continental shelf, between the beach and a depth of approximately 200 m, is covered with sediment which may be concentrated in an economically significant manner. (c) The deeper parts of the ocean have authigenic glauconite, phosphorite, and manganese deposits, together with pure calcareous and siliceous sediments. (d) Beneath all these, especially in areas adjacent to continents, are stratified rocks which may contain mineable vein minerals, coal, oil, or gas.

Only the first three of these environments will be considered here, since we are mainly concerned with surficial mineral deposits of organic or inorganic origin on the sea floor around New Zealand.

BEACHES

Continued erosion of the continents contributes large volumes of detrital sediment to the sea by rivers and by wave action along coasts. Owing to the pronounced decrease in carrying power of rivers as they enter the sea, much of the coarse fraction of their sediment load is deposited near the coasts.

By the action of waves and currents, sands are moved either along the coast or out into deep water. In the nearshore environment and on beaches, the constant motion to which mineral grains are subjected may lead to eventual fractionation according to properties such as density and size. Heavy minerals tend to be concentrated in certain zones, particularly at the bottom of sand deposits, due to net downward movement under the influences of fluctuating pressure caused by waves, and towards the backshore or inland side of the beach (Rao 1957; Mero 1964). Normally both wind action transporting lighter grains inland (Sevon 1966) and wave action transporting lighter grains seaward aid and accentuate this backshore concentration of heavy minerals (Fig. 1). The titanomagnetite deposits at Raglan in the

North Island, New Zealand, are chiefly dune sands where concentra-
tion is effected because the small, highly-spherical titanomagnetite
grains are more easily blown inland than the larger, less-spherical,
non-titanomagnetite components of local beaches (Kear 1965). Crevices
and fissures in the rock below a beach are regions of preferential
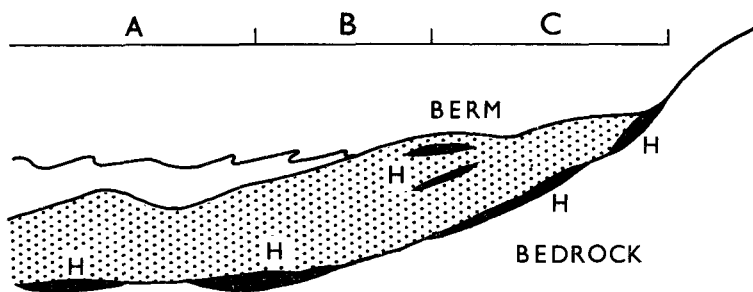concentration of heavy minerals (Mero 1964).

FIG. 1—Hypothetical beach cross section showing favourable locations for
heavy mineral accumulation (based on Mero 1964, fig. 1). H = Heavy
mineral concentrate; A = Offshore zone, below high tide line; B =
Foreshore, between high and low water; C = Backshore.

In New Zealand, the most obvious marine mineral resource is that
of beaches and associated dunes. The present and raised Pleistocene
beaches of the west coast of the North Island between Piha and the
Wangaehu River (Fig. 2) contain several million tons of titanomagnetite
derived from the andesitic rocks of Taranaki (Nicholson and Fyfe
1958; Kear 1965; Williams 1965) averaging 56 per cent iron (Kear
1966). Distribution of the sands (Fig. 2) north and south of the
Egmont region is achieved by longshore drift correlated northward
with the Westland current and southward with the D'Urville Current
(cf. Brodie 1960, Fig. 6). Also of economic interest are the ilmenite
beach deposits near Auckland, between Waikato Heads and Kaipara
Harbour (Fig. 2). Similar but much smaller concentrates of ilmenite
occur in places on the east coast of the Coromandel Peninsula (Kear
1965; Williams 1965).

Beaches of the west coast of the South Island of New Zealand (Fig. 2)
contain a variety of minerals of economic interest. The most notable
is ilmenite (forming up to 43.7% of surface minerals); smaller deposits
are of gold, magnetite (forming up to 33.8% of surface minerals),
rutile, zircon, monazite, scheelite, uranothorite, thorite, and zirconium
(Marshall, Suggate, and Nicholson 1958; Nicholson, Cornes, and
Martin 1958; Kear 1965; Williams 1965; Nicholson, Shannon, and
Marshall 1966). Garnet is found forming 50–80% of beaches in
Fiordland: cassiterite occurs in Perseverance Harbour, Campbell
Island, and sporadically on west coast South Island beaches (Williams
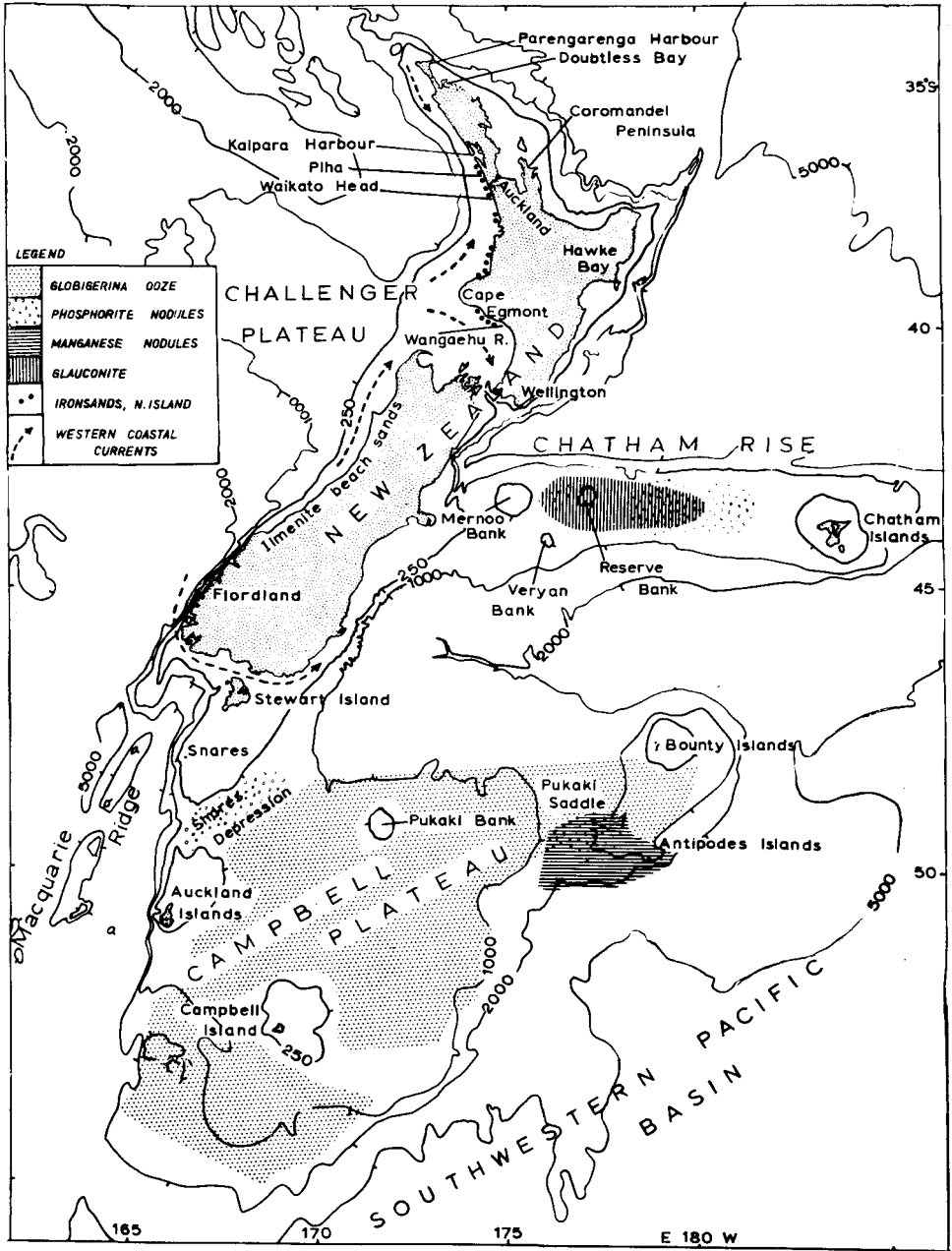1965; Nicholson, Shannon, and Marshall 1966).

FIG. 2—Distribution of selected mineral deposits on the sea floor around New Zealand. (Based on Brodie 1960; McDougall 1961; Norris 1964; Williams 1965; Summerhayes (in press) a, b.)

One of the commonest beach minerals is quartz. This forms up to 95% of mineral constituents in sands along the north-eastern coast of northernmost New Zealand where, at Parengarenga Harbour and other sites, it is mined as "glass sand". Unfortunately, the effort expended up to now in assessing the potential of quartz sands is minimal and in the words of Williams (1965, p. 267) "It may truly be said that we know exceedingly little about our siliceous beachsands."

Calcium carbonate in the form of comminuted shell fragments forms beach deposits in Northland which have been worked at Tokerau Beach in Doubtless Bay (Fig. 2) and elsewhere (Williams 1965).

Beaches are mined for a variety of minerals all over the world (Table I) and it is to be expected that New Zealand will one day utilise its large ilmenite and titanomagnetite beach deposits (New Zealand Department of Scientific and Industrial Research 1966, p. 11).

TABLE I—(based on Mero 1964). Sites of beach and inshore mining.

Country	Mineral
South Africa - - -	Diamonds
Japan - - - -	Magnetite
Ceylon - - - -	Ilmenite, rutile
Alaska (U.S.A.) - -	Gold
Oregon (U.S.A.) - -	Chromite, gold, platinum
Monterey (U.S.A.) -	Silica
Florida (U.S.A.) - -	Titanium minerals
California (U.S.A.) -	$CaCO_3$
Australia - - -	Heavy minerals
Iceland - - - -	$CaCO_3$

Poor grade quartz sands are mined in the U.S.A. for use in sand blasting and the manufacture of foundry moulds. Calcium carbonate from American and Icelandic beaches is used in cement manufacture or in the manufacture of lime for use in extracting magnesium from seawater (Mero 1964).

THE CONTINENTAL SHELF

One of the most important environments of heavy mineral concentration on the shelf is that of relict beach deposits formed at some lower sea level. As yet, little emphasis has been placed on exploration for these deposits although they must be assumed to exist around the New Zealand coasts.

A survey of the nearshore shelf off the west coast of the North Island, undertaken by the New Zealand Oceanographic Institute in 1959 and 1960, led to the discovery of off-shore ironsand concentration (Fig. 2) in 15 fms (27 m), where a 3–36% magnetic mineral fraction was obtained (McDougall 1960). Indications of a weak maximum in

35–40 fms (64–74 m) were also obtained during these cruises. Although these values are lower than those characterising the beaches and dune sands (*cf*. Nicholson and Fyfe 1958), it is the opinion of the writer that the surface concentration—averaging 2.1% magnetic minerals out to the 50 fm (91 m) isobath (McDougall 1960)—may reflect much greater concentrations at depth within the sediment. Such concentration is to be expected in view of the "normal" process of sinking of heavy mineral grains within a sand bed (Mero 1964) and their concentration at contacts between beach sands and underlying strata.

The evidence for off-shore concentration of ironsands off the North Island west coast in fossil beaches strongly suggests that similar mineral concentrates will be found elsewhere off the New Zealand coast. Since the beaches of the west coast of the South Island are environments of heavy mineral concentration, it is not unlikely that fossil beaches constituting large and valuable heavy mineral deposits will be found on the sea floor off this coast. This could be investigated most rapidly by conducting magnetometer surveys, preferably in co-ordination with sub-bottom profiling techniques.

Off-shore mining of placer deposits in drowned river beds is carried out off Indonesia and Thailand for cassiterite, off Japan for magnetite, off South West Africa for diamonds, and off Alaska for platinum (Mero 1964).

Terrigenous gravels and sands, even though of inhomogenous mineral composition, may have economic value if present in sufficient quantities. Gravels are at present obtained from Wellington beaches for use in the construction industry. Inexhaustible deposits of similar gravels together with all grades of sands are to be found on the continental shelf in shallow water (Cullen and Gibb 1966; Pantin 1966; Cullen and Gibb, in press; McDougall and Brodie, in press; McDougall and Gibb, in press, a, b; Summerhayes, in prep.) and could provide a major source of building materials in the future. River gravels at present fulfil this need but shelf deposits could become a more valuable asset if the exploitation of some river gravels has to be abandoned to avoid undesirable effects on the ground water systems which they overlie. Sands and gravels from the floor of San Francisco Harbour are extensively used in the construction industry (Mero 1964).

High concentrations of calcium carbonate occur off the northern tip of New Zealand where polyzoan and molluscan sands are thinly and unevenly distributed on the shelf (Summerhayes, in prep.). Extensive similar deposits characterise the continental shelf south of Stewart Island (Cullen and Gibb 1966), around the Snares (Summerhayes, in press, a), and the shelves around Campbell Island and the Auckland Islands (Summerhayes, in press, a). It is of interest that these areas (*cf*. Fig. 2) are far from major river systems and consequently receive little terrigenous detritus. Average carbonate content is 90% (*cf*. Summerhayes, in press, a, table 8).

The proximity of the southern deposits to major ports could make them commercially significant. Off-shore mining of similar deposits is carried out in the Gulf of Mexico, off the California coast, and off Iceland, where $CaCO_3$ is then used either for cement manufacture or as lime for the extraction of magnesium from seawater (Mero 1964).

The authigenic mineral glauconite, a hydrated potassium, iron, aluminium silicate containing 2–9% K_2O, is a potential source of potassium and its compounds which has to date been recorded in very small amounts from the shelf in Hawke Bay (Fig. 2) (Pantin 1966) and east of North Cape (Summerhayes, in prep.). These deposits have no economic significance.

THE DEEP-SEA FLOOR

Beyond the confines of the continental shelf around New Zealand is a broad, shallow, marginal plateau, the New Zealand Plateau, less than 500 fms (c.1,000 m) deep (Brodie 1964). Major elements of the New Zealand Plateau are the Chatham Rise, the Campbell Plateau, and the Challenger Plateau (Fig. 2).

Most terrigenous sediments not deposited on the shelf are moved, through submarine canyons, to the surrounding deep-sea floor. Migration routes of sediment are such that the Chatham Rise, Campbell Plateau, and Challenger Plateau are by-passed and receive only minor contributions of terrigenous detritus (cf. Brodie 1964). On the New Zealand Plateau a steady rain of organic skeletal material results in formation of extensive calcareous oozes, some of high purity. In some localities relatively high velocity bottom currents inhibit deposition, and formation of authigenic minerals such as glauconite, phosphorite, and manganese nodules occurs. These minerals and the calcareous oozes with which they are associated on the Plateau, will be considered in greater detail below.

GLAUCONITE

Norris (1964) found that glauconite is widely distributed in the sediments of the Chatham Rise and in some cases comprises more than half the total material, especially in the vicinity of Reserve Bank (Fig. 2) where concentrations of 80% are recorded.

On the Campbell Plateau, glauconite never forms more than 2% of the total sample (visual estimate); it is found in shallow regions near Pukaki Bank and Campbell Island, in the Snares Depression and the Pukaki Saddle (Fig. 2) (Summerhayes, in press, a). It occurs in negligible quantities only in sediments from the Challenger Plateau.

Glauconite occurs as discrete sand-sized particles. It is believed to be formed in slightly reducing micro-environments such as foraminiferal tests, pumice vesicles, faecal pellets, and discrete ferro-

magnesian mineral grains (Cloud 1955; Norris 1964; Pantin 1966). High bottom-current velocities common over the Chatham Rise (Norris 1964) but also locally developed in depressions on the Campbell Plateau (Summerhayes, in press, a) inhibit sedimentation.   These currents also remove quantities of autochthonous organic debris, apart from that retained in micro-environments.   Here, in mildly reducing conditions just below the sediment–water interface, bacteria reduce organic colloids releasing ferric and ferrous iron which, with illite clays, form glauconite (Norris 1964; Pantin 1966).

Chatham Rise glauconite is sufficiently concentrated to suggest that it might be economically exploitable.   The dependence of New Zealand agriculture on potash fertilisers to maintain soil fertility makes Chatham Rise sediments of interest.

The glauconites, when finely ground, show an initial potash release rate of 8.9m-equiv.%, much greater than terrestrial New Zealand glauconites with a rate of 4.05m-equiv.% (Norris 1964, table 3).   The sustained rate of potash release (Kc) is found to be about twice the value of terrestrial samples (Metson 1960).   Evidently finely ground Chatham Rise glauconite would be a better source of agricultural potash than terrestrial glauconite, but the cost of processing into marketable form must first be balanced against mining cost before its true potential can be assessed.   In view of the low estimated cost of mining sea-floor minerals, U.S. $1 per ton (Mero 1964, p. 114), mining of glauconite from Chatham Rise may yet prove economically feasible.

PHOSPHORITE

In view of the world's dependence on shrinking terrestrial phosphate resources the relative economic value of deposits of this material on the sea floor is bound to increase.   A valuable source of phosphate may be found in the deposits of phosphorite on the Chatham Rise (Reed and Hornibrook 1952; Norris 1964) and the Campbell Plateau (Summerhayes, in press, a) (Fig. 2).

Phosphorite is an authigenic mineral typically found as coarse pebble- or cobble-sized fragments referred to as nodules.   On the Chatham Rise phosphorite nodules are most abundant between the Chatham Islands and the Reserve Bank (Fig. 2).   Owing to sparse sampling coverage of the area and the limitations of sampling gear used, the extent of phosphorite deposits here has not been determined (Norris 1964), but an extensive sampling survey is now being carried out by a prospecting company.   Phosphorite nodules on the Campbell Plateau have been found in the Snares Depression and the Pukaki Saddle (Fig. 2).   At one sample site in the Snares Depression, small nodules up to 4 cm across comprised 90% of the sample.   All other samples contained a distinctly lower proportion of nodules (Summerhayes, in press, a).

The nodules are black, hard (about 5 on Moh's scale) and sub-rounded, some with a rough, dull surface, others glazed. The blackness is imparted by a glauconite crust (Norris 1964; Summerhayes, in press, a) surrounding phosphatised foraminiferal limestones. Chemical analyses (Reed and Hornibrook 1952; Summerhayes, in press, a, table 12) show that P_2O_5 contents of 20–30% are common, comparing favourably with phosphorite nodules from other localities. Collophane $(3Ca_3P_2O_8.Ca(CO_3,F_2,SO_4,O)nH_2O)$ and fluorapatite $(3Ca_3P_2O_8.CaF_2)$ are the main phosphate minerals (Reed and Hornibrook 1952; Norris 1964).

Authigenic phosphorite deposits are commonly found in environments where sedimentation is inhibited. Suitable sites are the Chatham Rise, Snares Depression, and Pukaki Saddle (Fig. 2), all of which are swept by vigorous bottom currents (Norris 1964; Summerhayes, in press, a). Conditions favouring phosphorite formation are oxidising environments and nutrient-rich bottom currents (Emery 1960). These conditions appear to apply to the Chatham Rise where minor amounts of phosphorite are being formed at the present day (Norris 1964). Phosphorite is not found forming at present on the Campbell Plateau (Summerhayes, in press, a).

Phosphorite nodules recovered from the Chatham Rise (Reed and Hornibrook 1952; Norris 1964) and Campbell Plateau (Summerhayes, in press, a) consist chiefly of phosphatised early to mid Tertiary foraminiferal limestones. It is inferred that sediment deposition at these localities has been negligible since nodule formation. The absence of late Tertiary and Recent Foraminifera supports the contention that phosphatisation was contemporaneous with ooze deposition or followed soon after. Since the mid Tertiary, conditions seems to have been unsuitable for phosphatisation. That physico- and/or bio-chemical conditions governing nodule formation have changed since nodule formation is indicated by the presence of thick glauconite crusts around nodules from the Snares Depression (Summerhayes, in press, a). It has been postulated that the change in environmental chemistry affecting phosphatisation, could be fundamentally related to temperature and that phosphate precipitation occurred in this region from the warmer waters of the mid and early Tertiary (Summerhayes, in press, a). This contention is borne out by experimental evidence (Clark and Turner 1955). Incomplete understanding of the complex mechanics of phosphorite precipitation makes further conjecture impossible (cf. Mero 1964).

On the Chatham Rise, the area at present covered by sites at which phosphorite nodules have been obtained is about 7,200 sq. miles. If there are (say) 1 lb of nodules per sq. ft then this area could contain about 90×10^6 metric tons of nodules.

In view of the proximity of these deposits to New Zealand and the relatively cheap costs of sea-floor mining with the appropriate equipment, the economic potential of these deposits cannot be too highly stressed.

MANGANESE NODULES

The resources of greatest recognisable economic potential on the deep-sea floor are manganese nodules (Mero 1964). Black, hydrous manganese dioxide concretions are distributed on the deep-sea floor as grains, nodules, slabs, rock coatings, and impregnations, and in less common forms (Mero 1964). Distinct layering is caused by preferential concentration of manganese layers, and either iron layers or deep-sea clay layers (Mero 1964). The nodules contain quantities of manganese, iron, copper, nickel, zinc, cobalt, rare earths, and other trace elements (Mero 1964; Summerhayes, in press, a, b) in significantly high concentrations in relation to seawater (Mero 1964). They are not only a tremendously large and important potential source of manganese but also of the trace elements associated with manganese. Mero (1964) has divided the Pacific into three major zones: a central zone in which the average manganese nodule concentration on the sea floor (estimated from photographs, cores, and dredgings) is 1.45 gms/cm², an eastern zone, and a western zone where the concentration is lower. The central region (Mero 1964, fig. 61, table 25) includes the Southwestern Pacific Basin, south and east of New Zealand. Thus, a large part of the manganese mineral resources of the Pacific lies on New Zealand's doorstep. The manganese nodules also occur in shallower water on the Campbell Plateau (Fig. 2) and Macquarie Ridge (Summerhayes, in press, a,b).

Manganese nodules are composed of authigenic manganese and iron minerals and form in oxidising environments where there is slow or negligible sedimentation (Mero 1964). Manganese may be derived from seawater or from dissolved volcanic effusives in seawater (Ahrennius and Bonatti 1965). From the association of manganese deposits on the Campbell Plateau with the Antipodes Islands volcanic centre, and a similar association between nodules and the volcanic Macquarie Ridge (Summerhayes, in press, a, b) it is inferred that the manganese deposits were formed from solutions of volcanic effusives in seawater. Preservation of the deposits is due to their formation in environments where sedimentation is inhibited by vigorous bottom currents.

Of the five stations at which manganese nodules were obtained around the Antipodes Islands, Sta. F 129 (Lat. 49°24'S, Long. 177°59'E) gave the highest bulk concentrate of manganese material, consisting chiefly of non-concretionary fragments of manganese rich material which may have formed a manganese pavement. At Sta. F 127 (Lat. 49°22'S, Long. 176°16'E) and Sta. F 129 in the Pukaki Saddle, manganese nodules are formed around previously existing phosphorite nodules (Summerhayes, in press, a, b). Since the phosphorite nodules consist of phosphatised mid-Tertiary foraminiferal oozes, then manganese deposition is late Tertiary or Recent (Summerhayes, in press, a,b). This accords with the hypothesis that the manganese is derived from seawater saturated with volcanic effusives derived from the Antipodes Islands or a related submarine source, since the Antipodes volcanism was probably Quaternary (Cullen 1967; Summerhayes, in press, a, b).

Should manganese minerals from the sea floor be commercially exploitable in the future, deposits of these minerals in 1,000–2,500 m on the southern edge of the Campbell Plateau may be more easily reached than deposits known to exist on the deep-sea floor in about 5,000 m. These deposits are also nearer to New Zealand than are the manganese deposits reported from the Southwestern Pacific Basin by Mero (1964).

Manganese nodules from the Macquarie Ridge probably do not form abundant resources of manganese minerals since the rugged topography of the ridge makes widespread deposits unlikely.

CALCIUM CARBONATE

Calcareous oozes with an average composition of 87% $CaCO_3$, reaching a maximum of 99% (*cf.* Summerhayes, in press, a, table 8), cover the surface of the Campbell Plateau (Fig. 2). In certain localities deposition is slow or negligible and, assuming that this does not apply for more than half the plateau, then at least 100,000 sq. miles are steadily accumulating $CaCO_3$. If a rate of accumulation of 1 cm/1,000 years is accepted (Mero 1964) then total accumulation since the Cretaceous is about 650 m. Even assuming that only a quarter of this thickness occurs, the total reserves of $CaCO_3$ are about 1×10^{14} metric tons.

Chief constituents of the ooze are the remains of Foraminifera and coccoliths which impart an average grain size of 3.5 φ (Md.). Sorting is best in the Snares Depression and the Pukaki Saddle (0.7 φ) and decreases to about 1.5 φ on other parts of the plateau (Summerhayes, in press, a, table 11). Mero (1964) indicates that this type of ooze would make extremely good cement rock. It is high in CaO and low in MgO, Na_2O and K_2O. The advantages of using globigerinal ooze in the manufacture of Portland cement are favourable composition, fine grain size, large surface area, the unconsolidated character of the deposits, and wide availability close to major ports.

Calcium carbonate is distributed in zones on the Chatham Rise (Norris 1964) and is concentrated on Mernoo Bank and Veryan Bank (Fig. 2) where coarse shell gravels occur. Most of the Chatham Rise is blanketed with silty or sandy sediment containing abundant Foraminifera. Usually (Norris 1964), these sediments contain between 25 and 75% $CaCO_3$ and are not as pure as those occurring on the Campbell Plateau.

On the Challenger Plateau, as on the Campbell Plateau, globigerinal oozes predominate (McDougall, in prep.). Less is known of the calcium carbonate content of these sediments and their value as $CaCO_3$ resources is difficult to assess.

MINING TECHNIQUES

Wire-line, bucket-ladder, and hydraulic methods are most commonly used in present submarine mining (Fig. 3). Adaptations of techniques at present used in shallow water are being developed for deep-water operations (Mero 1964). Bucket-ladder methods are used for tin mining off Thailand and Indonesia; wire-line methods are used for magnetite mining off Japan; hydraulic suction techniques are also used off Japan and elsewhere for gravel and sand supplies; airlift hydraulic dredges are used for diamond mining off South West Africa (Mero 1964). Of these four main techniques, only the wire-line method, using either dredge or grab techniques, has no depth limit. Other techniques are limited at present to about 200 ft.
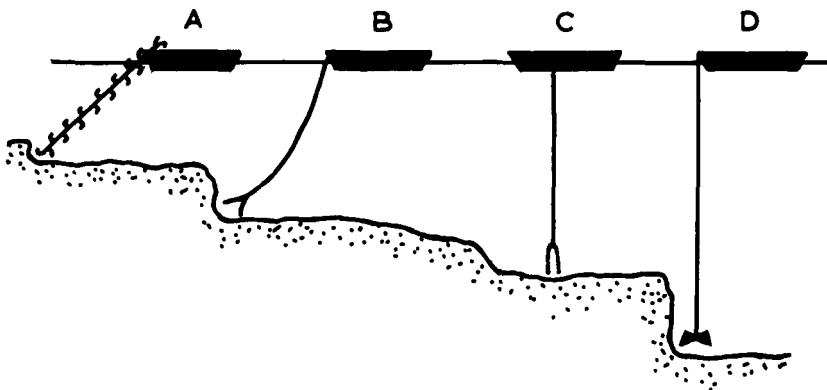

FIG. 3—Ocean mining techniques. (Based on Mero 1964, fig. 64.) A = Bucket-ladder dredge; B = Surface pump hydraulic suction dredge; C = Airlift hydraulic dredge (vacuum cleaner); D = Wire-line grab.

In the mining of deep-sea deposits the most effective technique at present available is the wire-line method. Dredging is the only economic form of this technique since the surface area covered by grabs is too small to warrant use in very deep water. Mero (1964) indicates that hydraulic "vacuum cleaner" techniques can be developed to cater for deep-sea mining although this is not yet technologically feasible.

The advantages of deep-sea mining can be summarised as follows (Mero 1964): it is the least expensive method of obtaining material already broken into small fragments that can be handled, sea transport, compared with land transport, is extremely cheap, and the grade of sea-bed mineral deposits is commonly uniform over large areas.

Mero (1964, p. 114) indicates that mining costs of U.S. $1–$2 per ton, including the cost of shipping to the nearest port, are realistic and conservative estimates for depths of up to 4,000 m.

CONCLUSIONS

The processing action of waves and on-shore winds causes or has caused concentrations of valuable minerals to accumulate along the New Zealand coast. Beaches and dunes on the west coast of the North Island contain tremendous reserves of titanomagnetite. Equally large reserves of ilmenite, and lesser quantities of magnetite, monazite, and other minerals are concentrated on the beaches of the west coast of the South Island. Discovery of off-shore iron deposits in fossil beaches (McDougall 1960) west of the North Island suggests that similar deposits will be found off the west of the South Island, thus considerably expanding the already known beach reserves. Although the submerged fossil beaches to the north do not contain more than 36% of magnetic minerals (McDougall 1960), it is to be expected that concentration of heavy minerals will increase with depth in the sediment. In view of the shallow nature of these deposits and their proximity to shore, they cannot be ignored in the assessment of New Zealand's mineral resources since present technological advances allow relatively cheap and easy mining of similar deposits elsewhere. Quartz sands are mined from beaches and offshore in shallow water on the north-east coast of the North Island, New Zealand, particularly in the entrance to Parengarenga Harbour.

Other than fossil beaches, the continental shelf does not seem to have much to offer in the way of mineral resources although sand and gravel deposits of varied composition are available all round New Zealand. Coarse sand-grade, relatively pure, calcareous deposits characterise the southern continental shelf and the shelves around the Auckland Islands and Campbell Island (Summerhayes, in press, a).

New Zealand is the emergent portion of the New Zealand Plateau, a large, fairly shallow (500–1,500 m deep) segment of the deep-sea floor around New Zealand (Fig. 2). Terrigenous sediments are transported through submarine canyons to the oceanic depths between and beyond elements of the New Zealand Plateau (cf. Brodie 1964). Challenger Plateau, Campbell Plateau, and Chatham Rise receive minute quantities of terrigenous detritus and are environments in which relatively pure calcareous oozes accumulate.

Chatham Rise is a current swept elevation where authigenic minerals are forming or have formed. Similar current-swept regions are the Snares Depression and Pukaki Saddle on the Campbell Plateau. Here authigenic manganese and phosphorite occur. Glauconite, which occurs in limited quantities on the Campbell Plateau and the New Zealand continental shelf, is found on the Chatham Rise in high concentrations, sometimes reaching 80% of the sediment. Metson (1960) and Norris (1964) have shown that these glauconites release potassium faster than do similar terrestrial glauconites from New Zealand. There is no doubt that if the technological problems involved in crushing the glauconite cheaply can be overcome, the Chatham Rise glauconite can provide a very important mineral resource for potassium and potash.

Phosphorite nodules on the Chatham Rise, if covering an area of 7,200 sq. miles at 1 lb/sq. foot, constitute a reserve of some 90×10^5 metric tons, of which the P_2O_5 content is some 20–30%. Deposits on the Campbell Plateau are smaller and may not prove economically valuable.

Manganese nodules occur at several localities in the Pukaki Saddle on the southern edge of the Campbell Plateau and at isolated localities on the Macquarie Ridge. These nodules, with their high concentrations of trace and rare elements, form potentially very valuable mineral resources. These deposits are nearer to New Zealand and shallower than similar deposits known to exist on the floor of the Southwestern Pacific Basin far to the east and south of New Zealand (Mero 1964). Further research into the extent of manganese deposits in this region is warranted by data at present available.

Fine-grained calcium carbonate occurs in unconsolidated form in rich deposits on the Chatham Rise, Challenger Plateau, and Campbell Plateau. Little is known of the distribution or composition of the globigerinal oozes on the Challenger Plateau. On the Chatham Rise the oozes contain 25–75% $CaCO_3$ and constitute impure reserves of this mineral. The Campbell Plateau globigerinal oozes are extremely pure, normally containing 87% $CaCO_3$. There is no doubt that these oozes constitute a tremendous reserve of $CaCO_3$ (in terms of future economic use) suitable for use in the cement industry, or as fertiliser, or for lime to be used in extracting magnesium from seawater, within easy reach of New Zealand ports. The total amount of $CaCO_3$ may be of the order of 1×10^{14} metric tons.

In assessing the value of mineral resources of the deep-sea floor, the capacity for depletion of the resource must also be considered. Glauconite is known to be forming at the present day on the Chatham Rise and Campbell Plateau and constitutes, in part, a self-replenishing reserve. Phosphorite is now being precipitated in very small amounts on the Chatham Rise (Norris 1964) but the formation of phosphorite nodules appears to have occurred only during the earlier Tertiary here and on the Campbell Plateau. Similarly, manganese deposits on the Campbell Plateau and Macquarie Ridge are fossil and not self replenishing.

The manganese deposits of the deep Southwestern Pacific Basin floor are much more extensive than those on the Campbell Plateau (*cf.* Mero 1964). If these deposits are in part formed by direct precipitation from seawater, with no direct volcanic source, then they may at least in part be self replenishing.

Ooze deposition on the Campbell Plateau is continuous and has been so since the early Tertiary as fossil oozes indicate (Summerhayes, in press, a). These deposits therefore are self replenishing.

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