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MARINE PHOSPHORITE PROSPECTS IN AUSTRALIA AND MARINE GEOLOGY IN THE B M R

by

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EVALUATION OF MARINE PHOSPHORITE PROSPECTS IN AUSTRALIA AND RECOMMENDATIONS FOR THE ESTABLISHMENT OF A MARINE GEOLOGY PROGRAM IN THE BUREAU OF MINERAL RESOURCES

by

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PREFACE

This report and the recommendations contained therein are the result of a visit by the author to the Bureau of Mineral Resources from August 9 to 31, 1965. It was the purpose of this visit to evaluate the possibilities of occurrence of marine phosphorites in Australian waters and to discuss general problems of marine geology pertinent to Australia. The report is based on the analysis of numerous documents, reports and publications, and on discussions with B.M.R. staff members, notably L.C. Noakes, J.J. Veevers, and J.A. Kaulback. Opportunity was provided for discussions with marine geologists from several Universities, with the Naval Hydrographic Office, and at the Fisheries and Oceanography Division, C.S.I.R.O., Cronulla.

SUMMARY

The limited information available indicates that although the intensive upwelling associated with eastern boundary currents cannot be expected in Australian waters, oceanographic and geological conditions may be favourable for the accumulation of marine phosphorite in three areas. As more data become available, others may be found. These areas, in order of importance, are: (1) banks off the northwestern shelf; (2) banks in the south-west Pacific near the Solomon and Bismarck Islands; (3) banks in the Coral Sea.

A program in marine geology is further justified by the need to extend the mapping and geological interpretation of the continent to its natural boundaries at the continental slopes. Quaternary alluvial mineral resources of the continental shelves are rapidly drawing industrial interest, and interest from the petroleum industry is already highly developed.

It is recommended that a systematic program of sedimentary, stratigraphic and structural mapping of the continental shelves be established in the Bureau. Such a program is naturally divided into two parts: (1) the mapping of the surface sediments and shallow marine stratigraphy and structure, mainly of the Cainozoic, and (2) the principally geophysical study of the deep structure of the continental margins. The former naturally belongs in the Geology Branch, and finds its economic justification in the study of phosphate and alluvial mineral resources. The latter is more strictly a geophysical effort.

A program and facilities for the marine geological effort are presented in this report.

Introduction

Until recently, the marine geology of the continental margins was an academic backwater that held interest for only a few investigators. In the last fifteen years, however, a sudden and spectacular increase in efforts and understanding has taken place, largely as a result of the interest and support of the petroleum industry. A majority of the large studies of the continental shelves has been initiated by industrial interest in sedimentary facies, and some were fully supported by petroleum companies. From this work has come the realization that the continental shelves not only form an integral part of the geology of the continent but also contain the key to much of its history, particularly the later phases. Moreover, increasing knowledge of the history and sediments of the continental shelves has indicated that other mineral resources than oil and gas, notably phosphates and alluvial mineral concentrates, may be present in abundance. The California Borderland phosphorites, the south-west African offshore diamond fields, and the alluvial gold of the Alaskan Shelf are examples of such resources that either are or can be economically exploited. Offshore exploration techniques have reached a high level of efficiency, and production methods are rapidly being developed. Major exploration activity can be expected in the next few years on many continental shelves. The Australian shelves are under serious consideration by several offshore mining companies.

Consequently, it is both timely and necessary for agencies charged with the responsibility for mapping and investigating the regional geology and mineral resources of coastal countries to extend their interests and efforts seaward. This has been recognized, among others, by the United States Geological Survey, which in 1963 established a program in marine geology with the following objectives (in part):

> " 1. To locate and delineate potentially useful mineral and fuel resources on and beneath the nation's continental shelves...."
>
> " 2. To determine the composition, structure and geologic history of the nation's continental shelves...."

The Geneva Convention concerning territorial waters and marine resources has also recognized the growing interest in offshore mineral resources in several of its articles which lay the groundwork for definitions of ownership.

This report is an analysis of problems in marine geology in Australia with special reference to marine phosphate resources. As a consequence of the considerations given above, it presents recommendations and a program of investigations to meet the demand for extended and systematic geological knowledge of the continental shelf and its mineral resources. More specifically, the questions under discussion are the following:

1. What is the potential for commercially exploitable marine phosphorite in Australian waters, and what constitutes an efficient program for its discovery and delineation?

2. What is the present level of marine geological effort in Australia, what is the program required to meet national demands, and what role should be assigned to the Bureau of Mineral Resources.

3. What specific program, staff, facilities and equipment are required to enable the Bureau to fulfill its mandate in this area?

MARINE PHOSPHORITES

Characteristics of California Offshore Phosphorites*

The only well known marine phosphorites are the deposits of the California Borderland which occur scattered over an area of about 36,000 square miles. In general, they are restricted to bank tops and prominences in depths from 60 to 2,000 metres. In such areas, phosphorite nodules cover the bottom with varying density, while ranging from sand size to more than 50 centimetres. Assuming a single layer cover, measured concentrations in well developed deposits have been found to vary from 5 to 30 lbs per square foot, with a narrow range of P_2O_5 contents around 29%. The total reserve has been estimated at one thousand million tons, of which probably at least 10% can be commercially recovered. The deposits are associated only with a highly glauconitic Foraminiferal sand, which can be easily removed by washing or screening. Both drag dredging and suction dredging are technically and economically feasible; the latter is significantly more efficient at production rates over 400,000 tons/year. The mining cost has been calculated at U.S.$4 to $7 per ton, depending on the depth of water. To produce 400,000 tons per year from 300 metres depth, an investment of US$3.5 million would be necessary, with an annual return of 30% after taxes.

Conditions of Marine Phosphorite Accumulation

The volume of formal and informal literature concerning the conditions of formation of marine phosphorite and its distribution in the oceans is large. Nevertheless, careful investigations are rare, and the present knowledge is fragmentary and unsatisfactory.

Marine phosphorite nodules have been dredged from the sea floor in many places, but only in one single case, in the California Borderland, has a moderately careful study been carried out. This deposit reappears frequently in all arguments but has not been exhaustively studied. Widespread circular reasoning in the comparison between modern and ancient phosphorites has confused the issues considerably.

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* Technical and economic analysis from John C. Mero (unpublished report.)

The following conclusions have been drawn from the available data by various authors.

1. Many marine phosphorite deposits, including the only large ones known, occur along the west coasts of continents and appear to be associated with equatorward eastern boundary currents. It may be noted that the recovery of phosphorite in marine samples and its identification are quite accidental, and that this distribution pattern may be apparent rather than real.

2. The better known deposits occur on isolated banks beyond the edge of the shelf rather than on the shelf itself. Conditions of little or no deposition invariably prevail.

3. Most deposits occur in areas with a high rate of dissolved inorganic phosphate supply and high biological productivity associated with upwelling water.

4. The process of phosphate precipitation itself is not well known. There appears to be much evidence that the phosphorite forms by replacement of a calcareous substrate rather than by direct inorganic or biogenic precipitation.

5. In all better known cases, the phosphorites (or their calcareous substrate) date back to the Miocene. There is no clear evidence that the process has continued throughout the Quaternary.

6. The formation of large quantities of phosphorite appears to be a slow process and long term stability of the topographic and oceanographic environments is required. Consequently, the continental shelves as areas of relatively high rates of sedimentation and widely fluctuating environments during the Pleistocene, are not favourable for significant phosphorite accumulation at the surface.

It is widely assumed that these observations indicate total or essential restriction of marine phosphorite to the west coasts of continents and to the trade wind zones. However, the available evidence does not, as yet, appear to require such a restrictive view point, and several alternatives have been insufficiently considered.

(a) Upwelling, even major and long-sustained upwelling, is not necessarily restricted to eastern boundary currents, but also occurs in the divergences of the equatorial current system. The productivity associated with this system has produced the guano phosphates of many west Pacific Islands.

(b) Upwelling and phosphate supply also can be topographically controlled and produced by local offshore winds and local current systems. South-east trades and both westerly and easterly currents in the equatorial region may produce sustained upwelling north of east-west trending islands and ridges.

(c) Relict Miocene phosphorites, not related to present conditions, may occur unconformably on submerged platforms and may be recoverable if no later deposition has taken place.

(d) Phosphatization of a calcareous substrate might take place without upwelling if in intermediate depth water masses of sufficient phosphate content pass over very slowly depositing calcareous sediments on deep banks.

Prospects for Marine Phosphorite in Australian Waters

No eastern boundary current appears to exist along the west coast of Australia. Along the north-west coast, however, the wind stress is favourable for upwelling at least during the south-east Monsoon, and recent data of C.S.I.R.O. indicate that such upwelling takes place on a modest scale. Upwelling is also reported from the eastern margin of the Banda Sea. Neither along the south coast nor along the east coast are conditions favorable for major upwelling, and no such upwelling has so far been reported.

At this time, it is reasonable to assume that the continental shelves do not offer a favourable environment for major phosphate accumulation, and that offshore banks and shoals or wide terraces on the continental slope offer the most promising habitat. The detailed morphology of the shelf margins of Australia is very poorly known. Promising bank areas occur along the north-western shelf from the Sahul Banks to Northwest Cape, but probably not farther south.* The southern continental margin is virtually unknown except for the shelves off south-eastern Victoria and Bass Strait, which are regions of Pleistocene sedimentation. Similarly, the shelf of New South Wales is unpromising, and the northern marginal seas are entirely above Pleistocene low sea levels.

Large bank areas occur in the Coral Sea, and possibly on the continental slope seaward of the Great Barrier Reef. Plateaus, ridges and banks are also common in the archipelagoes east of New Guinea (Solomon Islands, Bismarck Islands). In the last region local upwelling as noted under (a) and (b) in the previous section may be widespread. Phosphate deposits on numerous islands are witness of significant and sustained biologic productivity. In the Coral Sea, we must invoke some other process as indicated under (d): tongues of relatively phosphate-rich water at shallow depth have been observed.

From this very generalized summary the following areas appear to be of interest:

1. <u>The shelf edge and outer banks of the northwest coast from the Sahul Banks to Northwest Cape</u>. Upwelling, although not very strong, is present and has probably existed for a long time; structurally, the area appears reasonably stable, so that the numerous offshore bank areas, for a long time, may have existed under the required conditions of phosphate supply and low sedimentation rates.

2. <u>Banks and ridges of the Solomon and Bismarck Island groups</u>. Conditions appear favourable in many places for local but sustained upwelling, and the required topography is almost certainly present. Relatively deep levels, below 100 to 200 metres, will have to be explored, to avoid rapidly deposited Quaternary reefs and associated sediments. A disadvantage of this area is that long term stability is unlikely to have occurred.

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* It may be noted that traces of phosphatized carbonate occur on Ashmore Reef on the north-western shelf.

Moreover, the existing oceanographic and bathymetric knowledge is so fragmentary, that substantial reconnaissance work will be needed.

3. Banks and platforms seaward of the Great Barrier Reef and in the Coral Sea. In this area, banks and platforms appear to be widespread at levels where the sedimentation rate may be sufficiently low. The topography, however, is very poorly known. Moreover, there is no evidence for upwelling. In view of its economically favorable location, and the general uncertainty concerning principles of phosphorite formation, the region should be investigated.

Marine phosphorite nodules have so far not been found in Australian waters except for one, probably spurious, report. It must be emphasized, however, that even large deposits are unlikely to be found by accident because of their special location, and because dredges are required to recover the material. Moreover, the nodules are difficult to recognize and easily escape notice. The California Borderland phosphorites have been estimated to cover ten percent of an area of 36,000 square miles. Of many thousands of marine samples taken in this region, only approximatley 125 contained phosphorite. Systematic search in appropriate locations is necessary to establish the occurrence of this elusive material.

Program for Marine Phosphorite Investigations

The following program is recommended in view of the considerations presented above:

1. A fairly detailed topographic - sedimentologic study, including dredging and bottom photography, of the continental margin and outlying banks from the Sahul Banks to Northwest Cape.

2. A reconnaissance bathymetric and bottom sampling study of banks and ridges in the area from New Guinea to the Bismarck and Solomon groups. This work should be preceded by an analysis of available topographic and oceanographic data to estimate the position of the most probable areas of upwelling.

3. A similar reconnaissance study of banks and platforms in the Coral Sea. If either or both of these last two appear favorable, a more detailed study should follow.

4. Analysis of the phosphate content of all samples of the middle and outer continental shelf and outlying areas. It is not known whether phosphorite accumulations are surrounded by sediments with a significantly higher phosphate content than normal, but the approach is worthy of investigation. Since terrigenous sand and silt and skeletal carbonate dilute locally precipitated phosphate analysis should be restricted to a standard fine fraction (finer than 0.004 or 0.008 mm.)

5. The collection and analysis of bathymetric data, furnished by the Navy and other sources, should continue, in order to ascertain the absence or presence of bank areas. Considering the unsatisfactory state of our knowledge concerning the formation of marine phosphorite, all banks of sufficient size and isolation are potential prospects.

MARINE GEOLOGY OF THE CONTINENTAL MARGINS

Numerous recent studies of the sediments and history of the continental shelf and slope have clearly shown that these areas form an integral part of the geology of the continents. Formations and structures extend seaward across the shorelines, and the youngest geological history of the continents is better reflected in the deposits of the continental shelf than anywhere else. Moreover, recent discoveries of large petroleum reserves have served to underscore the economic importance of this hitherto neglected area. The exploration for marine phosphorite is an important part but not all of the task of mapping the geology and mineral resources of this area, which in Australia alone occupies approximately 1,000,000 square miles.

The surface portions of the continental shelves have been largely modelled by the repeated transgressions and regressions of the Pleistocene. During low glacial sea level valleys were excavated and subsequently filled with coarse fluviatile deposits while littoral sands accumulated near the shelf edge. The following transgression spread a generally thin blanket of littoral deposits across the width of the shelf, which in turn, during the maximum stand was covered with marine clays followed by the deposits of the prograding shoreline. In some shelves, several of such cycles can be recognized on acoustic reflection profiles. At the present time, transgressive littoral sediments are widely exposed at the surface of the middle and outer shelf, which are only locally covered by thin modern marine clays. These relict transgressive sediments show evidence of two temporary stillstands during the postglacial sea level rise in the form of extensive drowned beach ridges at approximately 45 and 65 metres below present sea level. Recently, extensive interest in the commercial possibilities of mineral concentrates in the Pleistocene shelf valleys and associated shoreline sands and younger drowned beaches has been stimulated by the discovery of prolific diamond concentrates on the south-west African shelf, and of gold gravels on the Alaskan shelf. Rapid high resolution acoustic reflection survey techniques and the development of simple offshore test drilling equipment have facilitated exploration. It must be expected that in the very near future interest in the potential of the Australian shelf for such alluvial heavy mineral concentrates as gold, diamonds, tin, wolframite, titanium and zircon, and thorium and uranium minerals will develop rapidly.

Offshore geophysical exploration for petroleum and offshore test drilling have yielded valuable information concerning the geology of the continental margins which has value and interest far beyond the limited interests of the petroleum industry. This data will have to be continuously monitored, collated and interpreted, and since it is concentrated in widely separated areas, will have to be interconnected by supplementary geophysical surveys.

In a number of cases it is already apparent that resources now exploited on land may extend below the sea floor, possibly under no more than a thin cover of unconsolidated sediments. The necessary technology for their exploitation will undoubtedly be developed in the foreseeable future. A program of investigation to find and delineate such ores will soon be required.

Until now, geological studies of the margins of the Australian continent have been few and generally limited in scope. The geophysical work of the oil industry and B.M.R., a joint survey of the Scripps Institution of Oceanography and B.M.R., and University studies in some nearshore areas deserve to be mentioned.

This dearth of information, for which an urgent need exists now in connection with the phosphate problem, and will exist even more in the near future when mining interest develops, makes an immediate systematic and efficient program of studies indispensable. It is advisable that the Bureau undertake, in the near future and on a reasonable scale, a program of mapping the continental margins in order to establish knowledge of the regional geology, structure and stratigraphy of this large portion of the continent. In order, furthermore, to assess and delineate its potential economic mineral resources, not only phosphorite, but also others, and to place itself in a position where knowledge and skill are available to encourage and guide successfully the development of these resources. In the process, much valuable knowledge will be obtained concerning the geological history of the continent and the nature of the transition between continent and ocean.

Definition of the Role in Marine Geology of the Bureau of Mineral Resources

The considerations given above lead to a suggested definition of the tasks of B.M.R. in marine geology and geophysics. Conveniently and naturally, the geological investigation of the continental margin can be divided into two parts, which differ in scientific and economic objectives, in program and procedure, and which, although mutually complementary, require a large degree of operational independence.

A. The mapping of the upper, largely unconsolidated and structurally simple Quaternary part of the continental shelf. This study, oriented towards the Cainozoic history of the shelf, finds its primary economic interest in phosphorite and alluvial ores. The skills and techniques required are mainly those of the sedimentologist and stratigrapher.

B. The mapping and interpretation of the deeper subsurface structure and the basement rocks, including the seaward extension of land geology, and the geophysics of the continental margins. The principal economic applications are in the field of petroleum geology, which provides much of the information, and later also in the exploration for basement ores. The skills and techniques are largely those of geophysics.

The group of tasks defined under B. appears a logical extension of the mandate of the Geophysics Branch, while those of group A. naturally fall under the Geology Branch. Although intercommunication and coordination are necessary, the two tasks are sufficiently divergent, and in part operationally incompatible, to require a high degree of mutual independence. The assignment covered by this report refers only to task A.

Hence, the following definition of B.M.R.'s role in marine geology as a logical extension of its mandate on land is suggested:

1. to map the sediments and shallow subsurface stratigraphy (mainly Quaternary) and structure of the continental shelf and adjacent slope and the borderland, and to study the Cainozoic geologic history of the continental margin.

2. to map and investigate the mineral resources of the upper, mainly unconsolidated portion of the continental margin with special emphasis on marine phosphorite, to study their genesis, and to encourage and guide their development.

3. to do basic research required and suggested by the investigations carried out under 1. and 2, and encourage and participate in marine geological studies by other Government agencies and Universities in Australia.

4. to collect, collate and interpret marine geological, oceanographic and bathymetric data collected by other investigators as they bear on the tasks listed under 1. and 2.

It is further recommended that the program following from this mandate be designed in accordance with the priorities for phosphorite studies as outlined earlier, and that emphasis be placed on this aspect as long as required.

An appropriate program along these lines, supplemented with geophysical studies, will place the Bureau in a strong position to extend the geology of the Australian lands to their natural limits at the edge of the continent, and will provide the capability to encourage and manage the development of offshore mineral resources.

Program, Staff, and Facilities for a Marine Geology Project

It must be recognized that marine geological investigations differ in several important aspects from regional geological studies on land. Whereas for the latter a large and reasonably adequate foundation of basic knowledge is available, the processes and historical aspects of marine geology are far less well established. Although recent work has established a level of knowledge from which generalized hypotheses and predictions can be drawn which are useful in the design of surveys, marine geological studies for years to come will contain large elements of basic research. On the other hand, the great uniformity of a predominantly depositional environment, subject largely only to world-wide historical changes, permits wider spacing of the observation network than on land. This combined with the use of continuous recording equipment, 24 hour working days and convenient transport allows mapping to proceed at a rapid rate, at a very reasonable price per square mile, notwithstanding ships cost.

Of the two principal approaches to mapping, - consecutive detailed blocks, or large-area reconnaissance with progressively increasing detailing, - the latter, because of the reasonable short-distance predictability of the environment, is preferable.

In successive surveys the overall density of observations can be increased, or selected type areas surveyed in detail and the findings extrapolated, and complex regions given more detailed coverage. When mapping at a scale of 1:1,000,000, no more than three field seasons, and generally only two should be required for most areas, and mapping can proceed at 20,000 to 50,000 square miles per year.

The nearshore environment to a depth of 10 to 20 metres, is one of great complexity, and usually dominated by very recent deposition. Detailed studies on a very small scale and large amounts of fundamental work are required for the investigation of this zone. It is suggested that this segment of the shelf be excluded from the regular mapping program, and that special studies of it be set up as required, or that the Universities be encouraged to make this their domain.

A Three-year Program

It is suggested that in the first year only one field party be organized, to spend three months at sea on a survey of the north-western shelf and outlying banks between the Sahul Banks and Northwest Cape. This party will require at least one additional field season one year later, but should at the end of the first year have some information on the phosphorite potential and a reconnaissance map of the area. A minimum of nine months between field seasons is necessary to keep abreast of the data accumulation, and maps and reports will require one to one and half years after the last cruise.

As soon as feasible, preferably in the second year, a second field party should be established. The principal task for this party should be a very general reconnaissance of the submarine topography and sediments of the Solomon and Bismarck Island groups, primarily emphasizing phosphorite. Unless this reconnaissance provides very definite encouragement, a second field season should be devoted to a similar study of the Coral Sea. After completion of both, a decision on further study will be possible.

It is strongly recommended that decisions on planning, programming, equipment and facilities be deferred until a project leader has been designated.

Staff

The program outlined above will require the services of five professional geologists, two of which should be formally trained in marine geological work to serve as project leaders. The team should include geologists with experience in physical oceanography, micropalaeontology, and sediment-petrology.

Each field team will require two geologists, one electronics technician, and three assistants. Of the last four, some can serve on both teams, and some may be hired for the field season only.

In order to cope with the production of survey data and samples, the following office staff will be necessary: one indexer-data processer, one, later two, draftsman, and two laboratory technicians.

Vessel

It is recommended that B.M.R. do not own or operate its own vessel. The required technical staff and base render such undertaking costly and cumbersome. Moreover, use for only six months per year is proposed, but even for all year operation costs would be excessive.

For the type of operation proposed availability of a suitable vessel in predetermined seasons and for six months per year must be assured. The operations required are only moderately compatible with some other oceanographic work and incompatible with most. Hence, use of Naval vessels or cooperative oceanographic research vessels will very seriously impede progress. Although they may be used as opportunity arises, the program should not depend on them.

Medium to small sized oceanographic research vessels with laboratory space winches and electronic equipment are available for charter. No vessel smaller than the following specifications should be considered, since efficient work under most weather conditions, and for 24 hours per day and 7 days per week needs minimum facilities of this kind.

Length:	95' - 135'
Endurance:	24 - 30 days
Range:	5,000 miles
Speed:	10-12 knots
Space:	6 scientist min.

Vessels much larger than this, as for instance a fully equipped ocean-going research vessel of the Discovery type, are not needed. The size of vessel suggested should be able to operate for between US$500 and 1,000 per day, while the large vessels run from US$2,000 - 3,000 per day. It may be noted that the cost per day supports continuous operation between ports.

The preferred type is an offshore oil exploration work boat, manufactured on the Gulf Coast in several standard sizes and with production line techniques. These vessels meet the above specifications for the lowest existing cost of construction. They have minimal below deck space, but a very large main deck designed to carry heavy weight. Scripps Institution uses one of these vessels, and provides laboratory, storage, and even berth space in portable seaworthy vans, which are standard off-the-shelf items. Such vans can be fully equipped at home, trucked to the dock, fastened and attached to utility lines, and after the cruise lifted off and returned to home base. They vastly reduce expensive turn-around and rigging time, eliminate the need for a staging area, and allow the entire on-shore portion of the operation to be located at Canberra.

Such a vessel can be leased, or if not available, be constructed for an appropriate firm in approximately six to nine months, and leased at a day rate of US$500-600 (US cost). During the off-season, the vessel will be fully usable in other marine work, and with a charter guarantee, a very favorable lease arrangement should be possible.

Marine Operations, Equipment, Laboratory

All of these items are conventional and standard practices and tested equipment exist. Improvisation is not necessary, and, as it will interfere with maximum efficiency, should be discouraged. After initial experience with existing procedures and equipment, modifications and improvements will be possible and necessary.

In the near future, offshore shallow stratigraphic drilling will almost certainly become necessary. It is possible to do this from the recommended vessel with existing light stratigraphic rigs with only minor modifications. The vessel will also handle small research submersibles, which should soon become conventional equipment.