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GEOLOGICAL ENVIRONMENTS OF
AUSTRALIAN DEPOSITS OF
PHOSPHATE AND GYPSUM

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PHOSPHATE

Introduction

As the natural phosphorus content in Australian soils is comparatively low at about 200 ppm, the application of phosphatic fertilizers is a necessity. The country relies for virtually all her raw phosphate rock on imports, mainly from Christmas Island, Ocean Island, and Nauru. Reserves on these islands are thought to be sufficient for not more than another 30 years at the present rate of consumption, but the consumption rate is increasing steadily. A search programme for new deposits was initiated by the Australian Government in 1957, and a number of Pacific Islands was investigated by the Bureau of Mineral Resources, without disclosing large deposits. In 1961 the Rum Jungle phosphate deposits in the Northern Territory of Australia were discovered, and although they do not meet the requirements they are interesting enough to be briefly described. Methodical study and exploration work by a mining company in conjunction with investigations by the Bureau of Mineral Resources ultimately led to the discovery of major sedimentary phosphate deposits by Broken Hill South Pty Ltd in 1966.

In this paper a short description is given of the geology of three deposits:

- a. Christmas Island, because it is the best studied and largest deposit of guano-derived island phosphorite, and still offers geological problems;
- b. Rum Jungle, because it is a rather unusual type of deposit, and of uncertain origin;

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- c. The newly discovered Duchess deposits, because they are of great extent and an example of the marine sedimentary type of deposits.

Christmas Island

Christmas Island, with an area of 80 km², is the top of a submarine volcanic cone which rises some 5000 meters from the bottom of the Indian Ocean, at a distance of 1440 km from the north-west coast of Australia and 300 km south of Java. The presence of phosphate deposits was recognized in 1887, and mining commenced in 1897. When in recent years demand began to considerably outstrip production, plans were made to increase the production, and the assistance of the Bureau of Mineral Resources was sought to provide the geological work preliminary to a comprehensive evaluation of the deposits.

The island rises in a series of wave-cut cliffs and terraces to a height of about 230 meters above sea level, with three isolated peaks reaching a maximum of 360 meters above sea level. There are 7 main terraces, but faulting complicates the picture somewhat, especially in the south. The terraces are the result of episodic and irregular uplift, whereby the southern part of the island was tilted more than the northern part. The upper three terraces form the island plateau, which is slightly centrally depressed.

The basement of the island is formed by basic volcanic rocks topped by pyroclastics. These are overlain by thin Eocene limestones and conglomerate, followed by a sequence of thick Miocene limestones which constitute the ramparts of the plateau and terraces. Much of the limestone in the central plateau area is dolomitised. Oligocene deposits are absent, and are probably represented by a hiatus.

The phosphate rocks form a blanket on the plateau and the terraces, and may be divided into incoherent phosphate and coherent phosphate. Incoherent phosphate is the superficial layer of brown, mottled, and white, soft, earthy, and granular phosphate containing oolites, and comprising virtually all the unconsolidated material on the island. The texture of this phosphatic soil varies from clayey to pelletoid, and all types contain pebbles and nodules of phosphate. Coherent phosphate, which

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probably forms less than 10 percent of the total tonnage, is massive, crustiform, and commonly brecciated rock, weathered down to blocks, boulders, cobbles, and pebbles; it includes white phosphatized limestone, light to dark coloured phosphatized volcanic rock, and cream to brown oolitic, pelletal, and fragmentary phosphate rocks commonly occurring as pebble phosphate.

In mining the phosphate, three grades are recognized, not so much on the basis of P_2O_5 content (which is high in all grades), but on the basis of the ratio of apatite to Fe-Al phosphate minerals. A-grade material is the purest in apatite and is used for the manufacturing of superphosphate, while the "overburden" of B and C grade material is stockpiled pending beneficiation. A-grade material is irregularly distributed over the limestone, and its phosphate mineral is carbonate-apatite. C-grade material forms the top layer of the soil profile, and contains mostly the iron-aluminium phosphate minerals crandallite and millisite, while barrandite is found over phosphatized volcanic rock. The B-grade material contains both apatite and iron-aluminium phosphate minerals. The reserves of all grades of phosphate rock exceed 200 million tons.

Although the present-day bird colonies are relatively small, and little can be seen of recent guano deposits, larger bird populations probably inhabited the island in the past, feeding off fish in the fertile waters in the areas of equatorial divergent currents. There is general agreement that the phosphate deposits have been derived from accumulations of their excreta.

Most commonly and simply it is thought that phosphatic solutions leached out of the guano reacted with the underlying rocks to replace them with apatite. During this process, chimneys and pinnacles were formed in the limestone. The island gradually grew by uplift, the birds occupying successively lower terraces. Climatic weathering of the apatite deposits resulted in an upper soil profile in which most of the apatite was transformed into iron-aluminium phosphate minerals, while sea spray introduced most of the trace elements. Replacement, void filling, weathering, and collapse gave rise to the varied textural suite of the phosphate rocks found today.

One variant to this basic theory invokes lateritic weathering of the phosphatized limestone to account for the generation of much of the iron-aluminium phosphate. Another variant suggests that the iron-aluminium phosphates in the soil profile were formed directly from the down-seeping guano solutions, and that when all the available iron and aluminium had thus been fixed, secondary apatite could be precipitated farther down as a replacement of limestone.

One recent theory claims that a marine phase of phosphatization must have existed during the atoll stage of the island. According to this viewpoint the phosphate developed as guano residue, as sub-aerially phosphatized limestone, and in enriched lagoonal waters by direct precipitation forming oolites, and by phosphatization of debris on the lagoon floor. The B-grade layer with its pebble phosphate is seen as the partly weathered remnant of the lagoonal phosphate rock, the C-grade soil with its iron-aluminium phosphate minerals would be the leached and decomposed residuum of the B-grade layer, and the A-grade rock would contain secondary apatite deposits precipitated from solutions derived from above. Only the plateau area would have represented the original site of phosphate deposition - the phosphate rocks on the lower terraces would have accumulated by mechanical transport from the plateau.

This theory has been strongly criticized on the following grounds: the apatite is fluor-deficient; the unit cell matches that of other oceanic deposits and is different from known marine apatite; the purity is too high; the oolitic texture is diagenetic and has developed in situ; the phosphate nodules near the surface were formed diagenetically from the incoherent phosphate, not vice versa (though this is a matter of opinion); fossils are extremely rare; there is hardly any bedding; and no other sediment types have been found.

Some of these objections should be reconsidered carefully. High purity, for example, is also found in some of the marine phosphorite beds in the newly discovered Duchess deposits in Queensland. The oolites may have had a diverse origin, and could well include submarine phosphatized lagoonal carbonate sands. The lack of other sediments may not be so embarrassing when it is realized that there was no significant terrigenous source area, and that carbonate sediments could easily have been completely phosphatized.

Bedding (including layers of coprolites) has been observed by several independent investigators. And the last word has not been said about the geochemical characteristics of the various types of phosphorite. Finally, it is almost inevitable that some of the phosphate rock was formed in the lagoon (accepting that a lagoonal phase did exist) either by precipitation or by replacement, as the restricted lagoonal waters must have become strongly super-saturated in dissolved phosphate that was being washed down from the guano deposits around.

It must be concluded that although the geology, mineralogy, and geochemistry of the Christmas Island deposits have been investigated in more detail than those of other guano islands, and the avian origin is beyond doubt, details of their origin are still open to much debate.

Rum Jungle

The Rum Jungle phosphate deposits, 65 km south of Darwin in the Northern Territory of Australia, were found in 1961 by officers of the Bureau of Mineral Resources while investigating radio-active anomalies during a search programme for uranium. Subsequent testing involving some 14,000 meters of auger drilling, rotary drilling, and diamond drilling as well as costeaning, outlined at least 2.3 million tons of ore within a range of 5 to 38 percent P_2O_5 and with an average of 10 to 12 percent P_2O_5 , distributed over eighteen deposits. Laboratory tests revealed that the phosphate rock is unsuitable for the manufacturing of superphosphate because of its high iron (5% to 30%) and aluminium (2% to over 10%) content and its very fine grain size. Pot tests showed that immediately available phosphorus to plants is low, but that calcination of the rock seems to offer some scope for local use.

The deposits are associated with folded hematitic siltstone and quartz breccia, hematitic sandstone, hematite rock, minor conglomerate and dolomite, and lenses of chlorite schist. They are generally stratigraphically overlain by carbonaceous and pyritic shale, and underlain by dolomite. These rocks are part of a Lower Proterozoic sequence including arkose, conglomerate, dolomite, greywacke, shale, and chert, and overlying Archaean granite gneiss. Outcrops of the phosphatic beds are scarce and poor, and their geological relationships were not too clearly understood at first. They have been variously considered:

- a. to be part of a gently folded and unmetamorphosed Upper Proterozoic sequence overlying the Lower Proterozoic rocks, and representing valley-fill breccias;

- b. to be an Upper Proterozoic or younger regolith, formed by weathering on a Lower Proterozoic surface;
- c. to be silicified reef limestone breccias interbedded with the Lower Proterozoic beds;
- d. to be part of the Lower Proterozoic sequence, as evidenced by the extensive drilling programme.

The origin of the hematitic quartz breccias is also a problem as yet not solved beyond argument. In places they can be traced into beds of unbroken interbanded hematitic mudstone and chert layers, and they may be a kind of large-scale riebung breccia rather than have a sedimentary origin.

Most high-grade phosphate rocks (those with more than 25 percent P_2O_5) are lilac or pink siltstone, some brecciated, some with mamillary structure, others containing apatite-filled ladder veins up to 10 cm wide. Much of the lower-grade material consists of quartz breccia with a hematitic and phosphatic siltstone matrix, some with a sandy phosphatic matrix. The principal phosphate mineral is fluorapatite, associated with hematite or goethite. The apatite is present in two phases: a fine-grained (0.005 mm - 0.030 mm) cryptocrystalline material enclosing dusty hematite; and a later phase of coarser-grained (about 0.1 mm) stubby euhedral crystals enclosing dusty hematite which commonly accentuates growth bands in the crystals. Most apatite is granular, but fibrous-radiating colloform structures also occur. The coarser, euhedral apatite was probably formed by recrystallization in situ of original collophane which was altered by fluorine-bearing fluids: the apatite is a fluorapatite, and the primary silica in the rocks shows extensive chemical corrosion.

At the surface, the phosphatic rocks in the weathering profile have changed to kaolinic-ferruginous clays in which iron-aluminium phosphate minerals have been formed in addition to remaining apatite. These secondary phosphate minerals include millisite, wavellite, and a member of the strengite-variscite series.

As is usually the case, the phosphate rocks are radio-active, containing up to 500 ppm U_3O_8 in surface samples.

The ore bodies occur as discontinuous lenses up to a few hundred meters long, and possibly also as pipe-like bodies. As the appearance of the phosphate rock is, with few exceptions, not noticeably different from that of the surrounding non-phosphatic beds, the outlines of the deposits are based on assay values.

The origin of the mineralization has not been solved. Three hypotheses have been suggested:

- a. the mineralization is hydrothermal;
- b. the deposits are of secondary origin, and were formed by late-Precambrian, or younger, weathering of underlying slightly phosphatic Lower Proterozoic dolomite;
- c. the deposits are metamorphosed Lower Proterozoic phosphate-rich ferruginous sediments.

Duchess area

The discovery of the large deposits of Cambrian marine phosphorite in North-west Queensland by Broken Hill South Ltd in 1966, was the result of careful preliminary planning and testing, some of it in conjunction with the Bureau of Mineral Resources. The history of the discovery, and the stratigraphy and structure of the deposits, are described by R.T. Russell elsewhere in the series of papers submitted to this Seminar.

The deposits are found in the Georgina Basin, a Palaeozoic shallow-marine depositional structure with an area of 320,000 km², and extending from north-west Queensland into the Northern Territory. The basin is about 960 km long and up to 480 km wide, and contains Cambrian and Ordovician marine sediments and Siluro-Devonian freshwater deposits.

Phosphatic rocks have been intersected in a number of drill holes scattered over the eastern sector of the basin, and are exposed along its eastern and south-eastern margins. Where found, they are associated with the base of a Middle Cambrian transgression (by whatever formation this base is represented), but they are well developed and of good grade only

in the lower Middle Cambrian formations, especially the Beetle Creek Formation.

The so-called Burke River outlier south-east of Duchess (which is 80 km south-south-east of Mount Isa), site of the recent major phosphate discoveries, forms an appendix to the main body of the Georgina Basin, and was separated from it at times by a topographic high. The outlier in itself is a small basin roughly 100 km long and 30 km wide, and bounded by faults which appear to have been pre-determined by established zones of weakness along which vertical movements (by monoclinial flexuring and by faulting) have recurred from the early Cambrian to as late as Tertiary times. Most of the Cambrian formations in the outlier are restricted to the area within the fault margins, but a few have transgressed beyond the boundary faults.

The geological history of the Burke River outlier may be summarized as follows: during the Lower Cambrian the basin of the Burke River outlier was formed by sag in the Precambrian basement, with hinge lines along the zones of weakness previously referred to. The depression thus formed was rapidly filled with ferruginous-arenaceous sediments of the Mount Birnie Beds, and the upper section of the Mount Birnie Beds transgressed beyond the basin boundaries to spread out as a blanket over the Precambrian borderland. This Lower Cambrian formation, in fact, levelled out the original relief by valley fill and blanketing.

During a following lower Middle Cambrian ingression, Thornton Limestone and cherty equivalents were spread out over the basin area and, in the east, partly beyond. This thin Thornton blanket furnishes a regional time datum over the whole extent of the Burke River outlier.

After a short temporary regression, a widespread Middle to Upper Cambrian transgression followed, gradually progressing from south to north (-east), and occasionally spilling out beyond the original boundaries of the basin. The basal lithological units of the transgressive series consists of bedded siltstone, siliceous shale, and chert; these are followed by limestones, and finally topped by a sandy siltstone unit. Time planes transect the lithological boundaries, and the established and published formation names are biostratigraphical units rather than lithological formations, and represent parva-facies within the magna-facies.

The phosphate deposits occur in the basal parts of the transgressive series, but are of significance only in the lower Middle Cambrian Beetle Creek Formation. The Burke River Basin was probably a restricted basin as suggested by the association of black (when fresh) chert and siltstone and strongly bituminous limestone. Sedimentation on the whole was slow and quiet, and the basin was connected with the open sea only in the south. It is likely that the carbonate facies was formed over low submarine banks in the central and also southern parts of the basin, and that the southern carbonate banks formed a low barrier between the basin and the open sea.

The phosphate deposits may have formed as a result of upwelling currents from the south (-east) in the manner originally described by Kazakov, and amended by others. An additional mechanism of precipitation may well have been the disturbance of chemical equilibrium owing to the intermingling of the upwelling water with the basin water which most likely contained concentrations of ion complexes different from those in the upwelling water. In the absence of any significant terrigenous sedimentation, currents could have had a strong winnowing effect leading to a residual concentration of precipitated phosphate pellets.

In the main body of the Georgina Basin, the deposition of phosphate took place probably on a much lesser scale, because the upwelling currents from the deep south-eastern seas would have lost much of their effect over the long distances of shallow epineritic environments involved.

GYPSUM

All the gypsum produced in Australia has come from deposits in and around saline lakes in the drier parts of the continent. Gypsum derived from the Proterozoic Bitter Springs Formation occurs in the cores of diapiric structures in the western part of the Amadeus Basin, central Australia, and crops out in other parts of the basin; this gypsum has not been utilized, and is not likely to be in the foreseeable future, because of its remote location.

Saline lakes occur in the southern half of the continent, except for the areas of higher rainfall on the west and south-west coastal fringe and the south-east of the continent (roughly east of longitude 147°E and south of latitude 36°S). The part of Australia in which the lakes occur has an annual rainfall of less than 55 cm, and over much of it the average is less than 25 cm. The annual evaporation in the same region is greater than 150 cm, and in parts exceeds 250 cm.

Most of the lakes occur in regions of low relief. They range from less than a kilometre to many kilometres in diameter. Depending on their location, some are flooded every year during the wet season, either by surface run-off or ground water infiltration; others, in the more arid parts of the continent, rarely contain water.

Gypsum is associated with other salts, mainly calcium carbonate and sodium chloride. In many lakes the gypsum forms only a small proportion of the total salts. Economic deposits of the mineral occur in several forms: Rock gypsum is massive and finely crystalline, and commonly shows growth layers; seed gypsum consists of small even-sized grains formed by mechanical disintegration of larger crystals, and commonly rounded because of rolling by wind; flour gypsum, gypsite, or kopi is a fine powder resulting from breakdown of more massive forms. A fourth form, granular gypsum, is either the first stage of the weathering of rock gypsum, or is the result of recrystallization of flour gypsum.

Rock gypsum is the form most commonly mined, as it generally contains fewer impurities than the others. It occurs under the floors of the lakes, and may extend well beyond their present edges. The rock gypsum layer may be as much as 5 metres thick, and is in turn underlain by sandy and muddy sediments, commonly containing organic remains, and limestone. It may directly underlie the lake, or may be covered by a layer of seed or flour gypsum, or a superficial layer of soil or silt.

Seed gypsum forms a layer on the floor of some lakes, but the largest deposits are wind-accumulated concentrations which form dunes on the down-wind side of the lakes. Some of the dunes formed this way are quite extensive. A dune at Lake Fowler, South Australia, is nearly 2 kilometres long, has an average width of 100 metres, and maximum height of 22 metres. The dunes are largely consolidated, and are partly vegetated.

Flour gypsum occurs on the surface of other deposits. It may be a metre thick on some dunes, and thicker than this on some lake floors. In some places, a dune of flour gypsum forms on the down-wind side of the seed gypsum dune. The flour gypsum is generally impure because of contamination by vegetation and wind-blown dust. Where it is worked, the gypsum is beneficiated by washing.

The gypsum in the lakes has undoubtedly formed by precipitation from evaporating solutions, but economic investigations of deposits have given little attention to the original source of the salts. Some of the lakes are close to the coast, and infiltrating seawater has probably supplied the salts for these, either by periodic influxes or infiltration through porous sands separating the lake from the sea. Complete evaporation of seawater would yield far more halite than gypsum, but halite is only a minor constituent of the deposits in many gypsum lakes. Precipitation of halite could be prevented by drainage of the brine from the lake or dilution of the brine by further influx of seawater before the brine reached the concentration at which halite is deposited. Precipitated halite could be removed by influxes and later drainage of sea or fresh water.

The gypsum in the inland lakes has undoubtedly been precipitated from groundwater which has flowed into the lakes. The gypsum could be derived either directly from the rocks of the catchment area, or from gypsum precipitated in earlier times or deposited in the weathering zone from vertically circulating solutions because of the prevailing hot arid conditions.

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